Effect of Polyethylene Film Lining and Gibberellic Acid on Quality and Shelf-Life of Banana Fruits

By
Hiba Elmukhtar Osman
B.Sc University of Khartoum (2002)

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Supervisor:
Prof. Abu- Bakr Ali Abu-Goukh

Department of Horticulture
Faculty of Agriculture
University of Khartoum
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This work is dedicated to my family and friends with all my love
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Abstract

The study was conducted to investigate the effect of polyethylene film lining, sealed or perforated, and gibberellic acid (100 ppm), by dipping the tip of the fruit only or the whole fruit, on quality and shelf-life of banana fruits.

Polyethylene film liners, sealed or perforated significantly delayed fruit ripening, maintained quality and extended shelf-life of bananas. Treatment with gibberellic acid (GA) either by dipping the tip of the fruit only or the whole fruit, resulted in more delay of fruit ripening and extension of shelf-life of banana fruits.

The sealed film liners and treatment with GA by dipping the whole fruit were more effective in delaying fruit ripening and extending shelf-life of bananas. That was reflected in more delay in the climacteric peak of respiration, peel color development, TSS accumulation, fruit softening and reduced weight loss during storage of bananas.
خلاصة الإطروحة

تم إجراء الدراسة لمعرفة تأثير تبطن العبوات بشرائح البولى إيثيلين المثقب وغير المثقب وحمض الجبريلين(100 جزء من المليون) عن طريق عمر قمة الثمرة فقط أو كل الثمرة على طول الفترة التخزينية وجودة ثمار الموز.

أدى استخدام شرائح البولي إيثيلين المثقبة وغير المثقبة بفعالية إلى تأخير نضج الثمار والحفاظ على جودتها وإطالة فترة تخزينها. كما أدت المعاملة بحمض الجبريلين بغرم قمة الثمرة فقط أو كل الثمرة إلى تأخير أكثر لنضج الثمار وإطالة فترتها التخزينية.

كان تبطن العبوات بشرائح البولى إيثيلين غير المثقب والمعاملة بحمض الجبريلين بغرم كل الثمرة أكثر فعالية في تأخير نضج الثمار وإطالة فترتها التخزينية. انعكس ذلك في تأخير اتدورة التنفس، وتأخير تلون القشرة الخارجية للثمار وترانا المواد الصلبة الذائبة الكلية وليونة الثمار وتقليل فقد الوزن أثناء تخزين ثمار الموز.
Chapter One

LITERATURE REVIEW

1.1. Origin, Importance and World Production:

Banana (Musa sp.) belongs to the genus Musa of the family Musaceae. The primary center of origin of bananas is thought to be Malaysia and from there it spread to the tropical world. Bananas are now cultivated throughout the tropics and in selected areas in the subtropics (Nakasone and Paull, 1998). The economic importance of the fruit is considerable and it became one of the most important fruits in the world trade. The ripe banana pulp contains mainly carbohydrates and supplies a good amount of energy (100 cal/100 g), and a fairly good source of vitamins A, B, B₂ and C (Salunkhe and Desai, 1984).

Banana is an important world food crop. It is the first exported fruit, in terms of value and rank second after citrus in terms of value (Salunkhe and Desai, 1984). The total banana production of the world has been estimated at 71.3 million metric tons per year, second only to the grape (FAO, 2004). The leading producing countries are: India, Ecuador, Brazil, Philippines, China, Indonesia, Costa Rica, Mexico, Thailand and Colombia (FAO, 2004). In Sudan, banana is grown successfully in every state, with total annual production of 74 thousand metric tons (FAO, 2004).

1.2. Respiration Rate:

Respiration is the overall catabolic process by which stored organic materials are broken down into simple end products with the release of energy. Respiration rate is an excellent indicator for the metabolic activity of the tissue, thus a useful guide of potential storage life of fresh fruits and
vegetables. The respiration rate is inversely proportional to the shelf-life of the produce; higher rates are associated with shorter shelf-life (Day, 1993).

The respiration process was classified in three phases by Phan et al. (1975): (a) breaking down of polysaccharides into simple sugars, (b) oxidation of simple sugars to pyruvate and other organic acids and (c) aerobic transformation of pyruvate and other organic acids into CO₂, water and energy. Protein and fat can also serve as substrate in the breakdown process.

Respiration rate per unit weight is highest for the immature fruit and then declines steadily with age. A significant group of fruit, including apple, banana, mango, papaya and tomato, undergoes a pronounced increase in respiration coincident with ripening. Such an increase in respiration is known as respiratory climacteric and this group of fruits is known as climacteric fruits (Wills et al., 1998).

Biale (1969) reported that the chemical changes that take place in fruits are directly or indirectly related to the oxidative fermentative activities, collectively referred to, as biological oxidation. He found that the stage of ripening corresponded closely with the climacteric peak in climacteric fruits.

Banana fruits show a typical climacteric pattern of respiration (Munasque and Mendoza, 1991). After harvest, at 20ºC, the respiration rate in 2 - 4 days rises from a steady value of about 20mg CO₂ / kg-hr in the hard green fruit to about 125mg at the climacteric peak and than falls to about 100mg as ripening proceeds (Palmer, 1971). Similar patterns were reported in guava (Bashir and Abu-Goukh, 2003), mango (Abu-Goukh and Abu-Sarra, 1993; Mohamed and Abu-Goukh, 2003) and tomato (Ahmed and Abu-Goukh, 2003).

The climacteric pattern of respiration of mango fruits was classified into four distinct phases based on the observed changes: (1) Pre-climacteric
phase, when the fruit is green and firm and CO₂ production is at minimum. (2) A climacteric rise, when sudden increase in CO₂ production is observed and fruit remains green and firm. (3) A climacteric peak, marked by a peak in CO₂ production. During this stage the fruit tends to break in color, becomes softer and develops an aroma characteristic of the fruit. (4) Post-climacteric phase, when CO₂ released shows a sudden decline and the fruit develops attractive color and aroma and becomes soft and edible ripe. After this stage, senescence sets in and the fruit is susceptible to infection by microorganisms, resulting in decay and death of the tissue (Krishnamurthy et al., 1960).

The climacteric behavior helps to determine the appropriate handling and storage protocols (Mitchell, 1992). The pre-climacteric period after harvesting is vitally important for importers and ripeners because bananas are transported before they are ripened. During this period, mature-green fruits have a low basal respiration rate and ethylene production is almost undetectable (Marriott and Lancaster, 1983), therefore longer pre-climacteric period are desired.

1.3. Fruit Ripening:

Ripening is the sum total of physico-chemical changes which make the fruits edible. These changes determine the quality of the fruit purchased by the consumer. Ripening is a dramatic event in the life of the fruit which transforms a physiological mature, but inedible plant organ into a visually attractive organ with characteristic aroma and flavor. Ripening marks the completion of development of the fruit and the commencement of senescence and it is normally an irreversible event (Wills et al., 1998). Ripening is a result of complex changes, many of them probably occurring independently of one another. The number, complexity and commercial importance of these changes make fruit ripening a special case of plant organ senescence (Wills et al., 1998).
Banana fruits are harvested at the mature-green stage and ripened in market area. Fruits that are allowed to ripen on the tree, often split and tend to be mealy (Kader, 1992). Maturity stage is judged largely by the visual appearance of the bunch and particularly by the angularity of the fingers (Simmonds, 1966). Bananas are harvested at the three-quarters, light full three-quarters, full three-quarters or full (Kader, 1992). Selection of the correct stage of maturity is an important factor, because it has great influence on subsequent storage and ripening conditions. The stage of fruit maturity depends on the time required to get them to the market. Fruits shipped for distant markets are usually harvested less mature than those shipped to closer markets (Kader, 1992).

Banana ripening is carried under controlled temperature and relative humidity. Ripening rooms must be well-insulated and provided with heating and refrigeration units. Vigorous air circulation is required to thoroughly disperse the ethylene and facilitate removal of respiration heat and accumulated CO₂. High humidity (90-95% r.h) is essential in ripening rooms to avoid fruit dehydration. Moisture may be introduced automatically in the form of steam, mist or spray of water at ambient temperature. In the absence of a special system, walls and floors may be wetted before closing the room to initiate ripening (Kader, 1992).

The objective of controlled ripening is to provide retail stores with bananas at a stage of ripeness desired by consumers. The state of ripeness is judged primary by peel color. The use of a 1 to 7 scale is common in the industry. At color No. 1, the finger is hard and completely green; No. 2, green but with some trace of yellow color; No. 3, about half green and half yellow; No. 4, more yellow than green; No. 5, yellow but with green tips; No.6, fully yellow; and No. 7; yellow flecked with brown sugar spots. Fruits should be ripened at least to color No.3 before delivery to retail stores, or ripening may not continue normally. Generally, the fruits are not riper than color No. 4
when shipped from the distribution center to the retail stores, because fruits may suffer handling injury if they are too ripe (Kader, 1992).

Ripening is initiated by the release of ethylene gas into the ripening rooms for 24 hours with fruit pulp temperatures at 15.5°C to 16.5°C. Sufficient gas is introduced into the room to provide a concentration, by volume, of 100 to 1000 ppm in air with vigorous air circulation. The ripening rate varies to some extent between lots. Cloudy conditions or low temperature during growth may slow the rate of ripening. Temperature conditions during handling and transit may also affect the ripening rate. The maturity of fruits affects ripening time. Hard green-fruits at the three-quarter stage require a noticeably longer time to ripen than fruits at full three-quarters (Kader, 1992).

1.4. Compositional Changes During Banana Fruit Ripening:

During ripening, the fruit passes through a series of overt changes in color, texture and flavor, indicating that compositional changes are taking place. Attainment of maximum eating quality of the fruit necessitates the completion of such chemical changes (Wills et al., 1998). Unripe fruits are usually starchy and acidic in taste, hard in texture and sometimes astringent. After ripening, they become sweet, soft and highly flavored, so greatly acceptable as human food (Mattoo et al., 1975). Some of these changes are described in the text below.

1.4.1. Color Changes:

The change in peel color from green to yellow is the most obvious change, which occurs during ripening of bananas due to the disappearance of chlorophyll, and serves as a rough guide to the stage of ripeness. Yellowing begins at or shortly after the climacteric peak and the fruit becomes fully yellow within 3-7 days at normal ripening temperature (Palmer, 1971).
The loss of green color is due to the degradation of the chlorophyll structure. The principal agents responsible for this degradation are pH changes (mainly due to leakage of organic acids from the vacuole), oxidation systems and chlorophyllase activity. Loss of green color depends on one or more of these factors acting in sequence to destroy the chlorophyll structure (Wills et al., 1998). Brady et al. (1970a) found that the peel tissue lost about 50% of its chlorophyll (originally 75mg/g fr.wt) in 2 days of exposure to 10 or 100 ppm ethylene and the chlorophyll content was near zero at 6-7 days. Looney and Patterson (1967) reported that chlorophyllase activity in banana peel increases sharply at the onset of the climacteric peak, and then falls to near zero in the post-climacteric period.

Color changes in ripening fruits have been associated by consumer with the conversion of starch to sugar (i.e. sweetening) and the development of the desirable attributes, so that the correct skin color is often all that is required for a decision to purchase the commodity. Such subjective assessment may be misleading. For example, if fruits such as bananas are ripened at higher than optimum temperature, full loss of green color does not occur even though the flesh is ripened (Wills et al., 1998).

Standardized color charts are used in the visual assessment of ripeness in many fruits, such as banana, pear, apple and tomato. The fruits are classified according to peel color by visually matching the peel color of the fruit against color charts (Wills et al., 1998). Kader (1992) stated that the color of the peel is used as an indicator of banana fruit ripening and a scale of 1 to 7 is generally used in the industry.

Objective measurements of color are possible using a variety of light reflection or transmission spectrophotometer. Hunter and Minolta color differences meters, which measure surface color, are widely used in research work (Wills et al., 1998).
1.4.2. Fruit Softening:

Fruit softening is characterized by changes in flesh firmness and has long been associated with fruit ripening (Dostal, 1970). These changes in fruit firmness determine shelf-life and quality of the commodity. Control of fruit texture is a major objective in modern food technology (Van Buren, 1970).

Fruit undergoes progress decline in flesh firmness with ripening. Abu-Goukh et al. (1995) observed a rapid decrease in flesh firmness during ripening of bananas. They found that more than 80% of firmness decline occurred over two days coincided with the climacteric peak of respiration. Similar patterns of changes were reported for mango (Abu-Goukh and Abu-Sarra, 1993; Mohamed and Abu-Goukh, 2003), guava (Bashir and Abu-Goukh, 2003), tomato (Ali and Abu-Goukh, 2005), pears (Lutton and Holland, 1986), apple, peach and apricot (Salunkhe and Wu, 1973) and date (Barrevedell, 1993).

The mechanisms by which fruits soften during ripening remain unclear and are subject to much speculations. Physiological studies and chemical analysis revealed a considerable loss of cell wall materials during ripening associated with fruit softening (Tendon and Kalara, 1984; Hall, 1964; Hultin and Levine, 1965; Nour, 1978). The interconversion of pectic substances is presumed to be involved in the characteristic softening which occur during fruit ripening. In the pulp of bananas, insoluble protopectin decreases from about 0.5 to 0.3% fr.wt and soluble pectin shows a corresponding increase during ripening (Palmer, 1971). Similar pattern was observed in tomatoes (Ali and Abu-Goukh, 2005).
Fruit softening during ripening is frequently attributed to the enzymatic degradation of cell wall materials (Ahmed and Labavitch, 1980a; Ali and Abu-Goukh, 2005). Polygalacturonase (PG) and cellulase activity progressively increase during ripening with a high correlation between the increase in enzyme activity and fruit softening and pectin esterase (PE) follows the climacteric pattern of respiration in mango (Abu-Sarra and Abu-Goukh, 1992), guava (Abu-Goukh and Bashir, 2003), pear (Ahmed and Labavitch, 1980b) and tomato (Ali and Abu-Goukh, 2005). The general observation is that softening is accompanied by solubilization of pectic substances involving the sequential action of PE and PG enzymes. This notion was supported by reports on changes in cell wall pectic materials during ripening of mango (Tandon and Kalara, 1984; Roe and Buremmer, 1981), tomato (Besford and Hosbon, 1972; Arad et al., 1983; Ali and Abu-Goukh, 2005), pear (Ahmed and Labavitch, 1980a), peach (Sterling, 1961), apple (McCready and McComb, 1954) and strawberry (Kertesz, 1951).

Very limited degradation of cellulose was reported to occur during softening of many fruits, including banana (Barnell, 1943), peach (Sterling, 1961), pear (Ahmed and Labavitch, 1980a) and apple (Kertesz et al., 1959; Knee, 1973). Tahir and Malik (1977) reported that cellulose and hemicellulose contents of mango fruit did not show appreciable changes during ripening, therefore, appear to have insignificant importance in textural changes during ripening. However, cellulose and hemicelluloses were reported to change substantially during softening of banana (Barnell, 1943) and date (Coggins et al., 1967; Hasgawa and Smolensky, 1971).

Besford and Hobson (1972) observed some degree of softening in tomato fruit commencement of PE and PG action. A well-modifying enzyme was reported by Karr and Albersheim (1969) to be an important prerequisite for the action of the polysaccharide-degrading enzymes. The current theory is
that PE removes the methyl groups of the galacturonic acid polymer (Lee and Macmillian, 1970), which enables PG to depolymerise the de-estrified polygalacturonoid chain and reduces its molecular weight (Benkova and Mankovic, 1976). Cellulase cleaves the β-1, 4 glucosidic bonds of cellulose (Babbitt et al., 1973). Recently Marin-Rodriquez et al. (2002) reviewed the role of pectate lyase in fruit softening. Pectate lyases (PL) catalyse the Ca^{2+}-dependent cleavage of de-esterified pectin, which is a major component in the primary cell wall of many higher plants. PL activity has been obtained directly from banana pulp with a substantial increase in activity during ripening (Marin-Rodriquez, 2001). Fruits of tomato, strawberry and grape all express PLs, where they play a significant role in fruit softening (White, 2002). The exact sequence of events and the contribution of these enzymes to softening in fruit are still not clear.

1.4.3. Total Soluble Solids:

Sweetness is one of the key flavor qualities of fruits and can be measured by the amount of total soluble solids (TSS) in fruits whose major carbohydrates pool is sugars (Kader, 1992). The most striking chemical changes, which occur during ripening of the banana, are the hydrolysis of starch and the accumulation of sugars (Palmer, 1971). About 20 - 25% of the pulp of the fresh green fruit is starch. By completion of ripening, the starch is almost completely hydrolysed, only 1 - 2% remaining in the fully ripe fruit. Sugars, normally 1 - 2% in the pulp of green fruits, increase to 15-20% in the ripe pulp (Palmer, 1971).

Total soluble solids were reported to increase during ripening of banana (Ibrahim et al., 1994), mango (Mohamed and Abu-Goukh, 2003), guava (Bashir and Abu-Goukh, 2003; Rodriguez et al., 1971) and date (Dowson and Aten, 1962). The total solids in the fruit were found to remain constant during
fruit ripening. The soluble solids, on the other hand were found to increase at the expense of insoluble solids (Krishnamurthy et al., 1960). Popenoe et al., (1958) attributed the increase in TSS during fruit ripening to the hydrolysis of the starch to sugars. This was then confirmed by Baile (1960).

1.5. Water Loss:

Water is lost from the fruits as they grow on the plant. The fruits may decrease in volume during the warm dry part of the day, but regain the moisture loss. After harvest the process of moisture loss continues, but now there is no way to replenish it. Moisture content of most fruits is high and weight lost during transport and storage can be a serious economic factor (Ryall and Pentzer, 1982). A loss in weight of only five percent will cause many perishable commodities to appear wilted or shrivelled, and this happens in few hours under warm, dry conditions. Even in the absence of visible wilting, water loss can cause loss of crispness, and undesirable changes in color and palatability may ensue in some commodities (Wills et al., 1998). Fruits ripen better, with not only better appearance due to the absence of shriveling, but also with better internal quality, at a relative humidity of at least 90 percent. The necessity for controlling humidity in banana ripening rooms in generally well recognized.

The amount of weight loss in storage will depend on the type of fruit, its size, composition and structure, the relative humidity in the storage room and the velocity of air movement (Ryall and Pentzer, 1982). There is a limited scope for modifying the tissue structure to reduce the rate of water loss. The most important methods of reducing the rate of water loss from the produce primarily involve lowering the capacity of the surrounding air to hold additional water. This objective is achieved by lowering the temperature and/or raising the relative humidity (i.e. by reducing the vapor pressure difference, VPD between the produce and air). An alternative to raising the
relative humidity is to provide a barrier to water loss by waxing or other hydrophobic coating or plastic film (Wills et al., 1998).

Water loss can be reduced effectively by placing an additional physical barrier between the produce and the surrounding air. This can also reduces air movement across the produce surface. Simple methods are to pack the produce into bags, boxes or cartons and to cover stacks of produce with tarpulins. Material such as polyethylene films are excellent vapor barriers since their rate of water transfer is low compared with that of paper or fiberboard, which have a high permeability to water vapor. The use of very thin plastic wrap and heat-shrink films for packing individual fruits is a relatively underused technology that can significantly increase the storage-life of many produce by greatly reducing their rates of water loss (Wills et al., 1998).

Packaging the produce in intact or perforated polyethylene packages or use of package film lining, result in high relative humidity inside the package and hence reduces weight loss in the produce (Elkashif et al., 2005). Polymeric film packaging has been extensively used to reduce water loss and to enhance fruit quality (Purvis, 1983; Eltayeb, 1995).

1.6. Control of Fruit Ripening:

It is well known that all fruits produce minute quantities of ethylene during development, however, climacteric fruits produce much larger amounts of ethylene during ripening than non-climacteric fruits. This difference between the two classes of fruits is further exemplified by the internal ethylene concentration at several stages of development and ripening. The internal ethylene concentration of climacteric fruits varies widely, but that of non-climacteric fruits changes little during development and ripening (Wills et al., 1998). Synthetic ethylene applied to fruits can cause a great burst of natural ethylene production. Ethylene, applied at concentration as low as
0.1-1.0 µl/l for one day, is normally sufficient to hasten full ripening of climacteric fruits. Now ethylene is considered as the natural ageing and ripening hormone (Kader, 1992).

Control of fruits ripening, initiation or delay, is generally dependent on factors that affect ethylene production or action. Treatment of pre-climacteric fruits with exogenous ethylene advances the onset of ripening. This response is used widely in commercial practice to achieve controlled ripening of fruits such as banana, which is picked and transported in a mature, but unripe state and ripened just before marketing (Wills et al., 1998). The action of ethylene must, however, be avoided for such fruit during storage and transport to prevent premature ripening.

Attainment of maximum possible storage life is the goal of storage studies. Usually, combination of treatments are resorted to. Thus waxing, polyethylene box lining, low O₂, high CO₂, ripening inhibitors and growth regulators are sometimes combined to prolong storage life. However, even with the optimum treatments for each for ripening inhibition, endogenous ethylene is always a problem. Delay of fruit ripening can be achieved by one or more of the following:

1.6.1. Low Temperature:

Low temperature can be used to achieve a delay in the onset of ripening in climacteric fruits. Lowering the temperature not only reduces the production of ethylene by the tissues, but also minimizes the rate of response of the tissue to ethylene action (Wills et al., 1998).

1.6.2. Ethylene Exclusion and Removal:

The removal of ethylene from the atmosphere surrounding the commodity is the preferable method of preventing deterioration of produce sensitive to this gas. In great majority of cases, high levels of ethylene in
storage and handling areas can be avoided by removing sources of ethylene. Rigorous attention to sanitation will remove overripe and rotting produce, a source of ethylene. Simple ventilation of storage and ripening rooms can reduce ethylene concentrations. An exchange rate of one air change per hour can readily be provided by installing an intake fan and a passive exhaust (Kader, 1992).

Removal of endogenous ethylene was the first benefit ascribed to the hypobaric or low-pressure system of storage. The shelf-life of bananas can be extended considerably by low-pressure systems (Abu- Goukh, 1986; Burg and Burg, 1966). Banana ripening is completely inhibited if fruits are stored at one-fifth atmospheric pressure in pure oxygen so that atmospheric tension of oxygen is maintained. The inclusion of small amount of ethylene in the atmosphere overcomes the inhibitory effect of the reduction in pressure (Burg and Burg, 1966). Abu- Goukh (1986) reported that ethylene production and respiration activity of bananas held at 20ºC in gas mixtures of 1 to 10% O₂ under one fifth atmospheric pressure were considerably depressed, no climacteric was apparent and fruit remain green and firm until the end of the 14 days storage period. They showed a rapid increase in ethylene production and respiration activity and started to ripen normally almost immediately after being transferred to air. Apelbaum et al. (1977) found that the slowing of banana ripening is inversely related to atmospheric pressure of storage.

1.6.3. Inhibition of the Effects of Ethylene:

Delaying of fruit ripening can be achieved by modified atmosphere (MA) or controlled atmosphere (CA) storage. Ethylene production and respiratory activity of banana fruits at 20ºC in gas mixture of 1 to 10% O₂ were greatly depressed. No climacteric was apparent and fruits remained green and firm until they were removed to air after 18 days, where they showed a rapid increase in ethylene production and respiratory activity and
started to ripen immediately (Abu-Goukh, 1986). Smock (1967) reported that banana would be effectively stored for 3 weeks at CA conditions of 2% O2 and 6 to 8% CO2 at 15°C. Many of the beneficial results of modified atmosphere storage cannot simply be attributed to a reduction in respiration. The greatly increased storage life is attributed to a reduction in the rate of natural ethylene production by the bananas, decreased sensitivity of the fruit to ethylene and inhibition of CO2 of ethylene action (Wills et al., 1998).

The use of plastic films in achieving modified atmosphere is increasing. Polyethylene box liners, either sealed or perforated, have been used for several years in the storage of apples and pears, but only to limited extent with other produce. Perforated polyethylene films are commonly used to minimize weight loss, reduce abrasion damage and delay fruit ripening (Elkashif et al., 2005; Wills et al., 1998). It has been shown that bananas packed in polyethylene-lined boxes have a longer shelf-life than control fruits (Kader, 1992). Smock (1967) also showed that ‘Dwarf Cavendish’ banana could successfully be stored for 7 to 10 days in perforated or sealed bags at ambient temperatures. The sealed bags usually resulted in better keeping quality than perforated ones. Field handling of bananas combined with placing hands in polyethylene films bags for transport was found to be most suitable technique to reduce wastage of bananas after harvest (Silvis et al., 1976). These workers suggested that wrapping of bananas in polyethylene bags helps to reduce bruising due to a lubricant effect of the film and due to the high humidity around the fingers, preventing damage areas from drying out and becoming severely necrotic.

1.6.4. Chemical Removal of Ethylene:

Ethylene, which developed in CA storage chamber, had to be removed to get extended storage life; otherwise endogenous ethylene gas over powered the low O2 effect (Smock, 1967). Removal of ethylene gas can have
additional benefit on extending green-life of bananas, under both ambient and modified atmosphere conditions (Scott et al., 1970; Liu, 1976; Abu-Goukh, 1986). Ethylene can be removed by a number of chemical processes.

Potassium permanganate (KMnO₄) is an oxidizing agent quite effective in reducing ethylene levels by oxidizing it to CO₂ and H₂O (Kader, 1992). Since KMnO₄ is non-volatile, it can physically be separate from the produce, thus eliminating the risk of chemical injury (Wills et al., 1998). KMnO₄ is a chemical, which has long been used to remove ethylene from the storage atmosphere (Salunkhe and Desai, 1984). Scott et al. (1970) showed that bananas in film bags containing KMnO₄ (to absorb ethylene) were firmer than fruits in sealed bags with Ca(OH)₂ (to remove CO₂). It was estimated that about two weeks additional storage life was obtained by packing KMnO₄ with the fruits. Many porous materials have been used to manufacture permanganate absorbers, including vermiculite, pumice and brick. A commercial preparation called ‘Purafil’, which is alkaline KMnO₄ on silicate carrier produced by Mabson Chemical Co., proved effective in complete absorption of ethylene from banana held in sealed polyethylene bags (Liu, 1970). Abu-Goukh (1986) reported that ‘Purafil’ lowered the rate of ethylene production by about 15 to 30% in CA storage even after the ‘Purafil’ was removed and treatment were transferred to air. The reduction of ethylene was reflected on a slight delay in ripening. The use of KMnO₄ in conjunction with modified atmosphere storage in polyethylene bags was found to delay the ripening of bananas by up to 21 days (Scott et al., 1970).

Ozone, a very potent oxidizing agent, can also be used to remove ethylene from the atmosphere. The effects of ozone on fruits and vegetables can, however, be very harmful (Kader, 1992). Charcoal air purifiers, especially if brominated, can be used to absorb ethylene from air. These systems are largely confined to use in the laboratory, since potassium permanganate absorbers are cheaper and more widely available (Kader, 1992).
Silver ions applied in aqueous solution as AgNO₃ inhibited ethylene synthesis and ripening of mature banana slices (Saltveit et al., 1978). The inhibition of ripening and ethylene synthesis by the silver ion was evident in tissue treated with sufficient exogenous ethylene to elicit both responses in control tissue. However, several parameters of banana ripening were not inhibited at concentration of the silver ion, which severely inhibited others.

1.6.5. Growth Regulators:

Ethylene is a plant hormone that acts in concert with other plant hormones (auxins, gibberellins, kinins and abscisic acid) to exercise control over the fruit ripening process (Wills et al., 1998). Ethylene is important in the system for initiation of fruit ripening, but other factors (such as IAA, ABA and GA) may also be important in the timing of the onset of the sequence of ripening changes (Salunkhe and Desai, 1984). Post-harvest dip of bananas in aqueous solution of gibberellic acid (50 ppm) and kinetin (2 ppm) retarded ripening, while indole acetic acid (IAA) and abscisic acid (ABA) had the opposite effects (Desai and Deshpande, 1978). The differential effects of growth regulators on banana ripening were interpreted through their probable action on five enzymes catalyzing the ripening process (Desai and Deshpande, 1979).

Gibberellins are a group of growth substances known to retard ripening and senescence of fruits. They are synthesized in young fruits by the developing seeds (Leopold and Kriedemann, 1975) and are believed to participate in promoting early fruit growth. In mature fruits, gibberellins have been reported to be involved in many of the physiological steps leading to ripening and senescence. Dailly (1969) has reviewed the effect of gibberellic acid (GA) on the ripening of fruits.
Post-harvest dip of 3 cultivars of bananas in aqueous solutions of gibberellic acid (50 ppm) retarded ripening, judged from rates of changes in various physical and chemical constituents (Desai and Deshpande, 1978).

Several workers have shown that dipping mango fruits in gibberellins delayed fruit ripening (Feungchan, 1992;; Khader, 1992 and Manzuno and Campbell, 1996). However, in mango tissue slices, Singh et al. (1976) observed that GA accelerated the ripening of the slices by inducing ethylene production. He attributed this contradiction to the distribution of GA in tissue slices following vacuum infiltration.

The effect of GA seems to be mainly on color development, although other aspects of ripening process are also affected. GA delayed chlorophyll degradation and fruit softening in banana (Vendrell, 1970) and mango (Khader, 1992), decreased sugar accumulation, TSS and sugar/acid ratio in banana (Ahmed and Tingwa, 1995) and mango (Murthy and Rao, 1982). They concluded that fruit ripening can be controlled chemically without lowering the quality of the fruit.

GA retarded colour development in banana (Ahmed and Tingwa, 1995), tomato (Dostal and Leopold, 1967) and orange (Coggins and Lewis, 1962). GA reduced senescence in terms of green color retention in citrus peel (Greenberg et al., 1987) and inhibited degreening in cultural peel segments (Garray, 1990). Fletchner and Osborne (1965) suggested that GA regulates proteins and nucleic acid synthesis and thus retains the chlorophyll moiety. Gibberellins have also been reported to delay the onset of the climacteric rise in banana (Awadd et al., 1977; Ahmed and Tingwa, 1995) and inhibited respiration rate in apple (Lu and Lu, 1992). Lewis et al. (1967) explored the mechanism of action of GA on ‘Navel’ oranges and found that treated fruits had a lower ratio of monovalent to divalent cations and a higher Phosphorus
level than the control. They proposed that GA maintained the integrity of mitochondrial membranes.

The mechanism by which GA retards ripening has not been clearly elucidated, but it may be supposed to act at the gene level, or through modifying the effect of other hormones. Evidence by Valdorino et al. (1967) suggested that GA significantly influenced the level of auxins, in plant tissues. Scott and Leopold (1967) have also reported that GA and ethylene have opposite effects on fruit ripening and senescence. However, unlike auxins, gibberellins did not counteract the stimulatory effect of previously applied ethylene on mango (Singh, et al., 1976).
References


The Effect of Polyethylene Film Lining and Gibberellic Acid on Quality and Shelf-Life of Banana Fruits

2.1. Introduction

Banana (Musa sp.) is a commercially important fruit crop in the world trade. In Sudan, banana is the most popular fruit for its nutritive value, low price and availability all year round. It is grown in almost every state, with annual production of 74 thousand metric tons (FAO, 2004). Bananas in ripe state are used as a dessert fruit. The ripe banana pulp contains mainly carbohydrates and supplies a good amount of energy (100 cal/100g) and a fairly good source of vitamins A, B<sub>1</sub>, B<sub>2</sub> and C (Salunkhe and Desai, 1984). Although Sudan has great potential to produce high quality bananas, the post-harvest handling practices are still not taken care of by both producers and distributors. These practices need a lot of improvement for development of a sound banana trade both for local and export markets. Bananas are usually harvested at the mature-green stage and transported to distant markets and are ripened afterwards. During transit, they should remain green and firm for one to two weeks, depending on market distant. The green-life of bananas can be extended by transporting them under optimum conditions of temperature, relative humidity and composition of the atmosphere, elimination of ethylene and use of ripening retardants (Kader, 1992). Modified atmosphere (MA) storage retards ripening and senescence associated with biochemical and physiological changes, reduces post-harvest losses, and extends storage life of some horticultural crops (Kader, 1992). The
primary effect of modifying the concentration of O₂ and CO₂ in the storage atmosphere are thought to be the reduction in rate of respiration and associated processes. Reduction of partial pressure of O₂ and elevation of partial pressure of CO₂ can reduce the rate of natural ethylene production by the fruit and decrease the sensitivity of the fruit to ethylene action (Wills et al., 1998).

The use of plastic films in achieving modified atmosphere is increasing. Polyethylene box liners, either sealed or perforated, have been used for several years in storage of apples and pears, and now is extending to other commodities (Kader, 1992; Elkashif et al., 2005). Perforated polyethylene films are commonly used to minimize weight loss, reduce abrasion damage and delay fruit ripening (Elkashif et al., 2005; Wills et al., 1998). It has been shown that banana packed in polyethylene lined boxes have a longer shelf-life than control fruits (Kader, 1992).

Gibberellins (GA) are a group of growth substances, known to retard ripening and senescence of fruits. The effect of GA seems to be mainly on color development, although other aspects of ripening processes are also affected. GA delayed chlorophyll degradation and fruit softening (Vendrell, 1970; Khader, 1992) and decreased sugar accumulation, TSS and sugar/acid ratio in banana (Ahmed and Tingwa, 1995) and mango (Murthy and Rao, 1982).

This study was conducted to investigate the effect of polyethylene film lining and gibberllic acid treatment on quality and shelf-life of banana fruits.

### 2.2. Materials and Methods

#### 2.2.1. Experimental Materials:

"Dwarf Cavendish" banana fruits were obtained from a private orchard in Senja area 400 km south of Khartoum. Fruits were harvested at the "full
three quarters" mature-green stage. The bunches were dehanded and divided into fingers. The fruits were selected for uniformity of size and freedom from blemishes. Fruits were washed with tap water to remove latex and dust, treated with sodium hypochlorite (500ppm) to reduce fungal infection and air-dried.

2.2.2. Fruit Treatment:

The banana fruits were distributed among the seven treatments (50 fruits each) in a randomized complete block design with three replications. The fruit were treated with 100ppm gibberellic acid (GA) (Sigma Chemical Company) applied either by dipping the whole fruit or only the tip of the fruit for three minutes and then air-dried. The control were dipped in distilled water and air dried. The fruits were then packed in carton boxes lined with either perforated or unperforated (sealed) polyethylene films (0.0015mm) or left without lining as control. All boxes were stored at 18 ±2°C and 90-95% relative humidity.

2.2.3. Respiration Rate:

Respiration rate was determined daily during the storage period in 10 fruits of each treatment. The total absorption method of Charlimers (1956) was used and respiration rate was expressed in mg CO₂ / kg-hr.

2.2.4. Peel Color:

Peel color changes were determined daily in the same 10 fruits used for respiration. The banana color chart developed by Chiquita of United Brands Company (Chiquita Brands Inc., 1975) was used in estimating the color score. Color index No.1, green; No.2, green-trace of yellow; No.3, more green than yellow; No.4, more yellow than green; No.5, yellow with green tip; No.6, all yellow and No.7, yellow flecked with brown.

2.2.5. Weight Loss:
Weight loss was determined daily in the same 10 fruits used for respiration and peel color. A digital sensitive balance was used to determine fruit weight. The weight loss was calculated according to the formula:

\[ W_1 = \left( \frac{W_0 - W_t}{W_0} \right) \times 100\% \]

Where \( W_1 \) is the percentage weight loss, \( W_0 \) is the initial fruits weight and \( W_t \) is the weight of the fruits at the designated time.

### 2.2.6. Flesh Firmness:

Flesh firmness was determined in two fruits picked randomly from each treatment, other than those used for respiration and color estimation, at two-day intervals during storage. Magness and Taylor firmness tester (D. Ballauf Meg. Co) equipped with 8mm diameter plunger tip was used. Two reading were taken on opposite sides of each fruit after the peel was removed. Flesh firmness was expressed in kilograms per square centimeter.

### 2.2.7. Total Soluble Solids:

Total soluble solids (TSS) were determined directly from the fruit pulp in the fruits used for fresh firmness at two-day intervals during storage, using Kruss hand refractometer (model HRN-32). Two readings were taken from each fruit and the mean values were calculated and corrected according to the refractometer chart.

### 2.2.8. Statistical Analysis:

Analysis of variance, followed by Duncan’s Multiple Range Test, with a significance level of \( P \leq 0.05 \) (Gomez and Gomez, 1984) were performed on the data.
2.3. Results and Discussion

The use of polyethylene film liners, sealed or perforated, significantly delayed fruit ripening, maintained quality and extended shelf-life of bananas. The sealed polyethylene film liners resulted in better keeping quality than the perforated ones. Elkashif et al. (2005) reported that banana fruits held in intact polyethylene packages had the longest green-life, followed by those held in perforated ones and unpacked fruits had the shortest green-life. The process of respiration of fruits packed in polyethylene films resulted in a modified atmosphere with lower O₂ and higher CO₂ concentrations. Low O₂ concentration suppresses ethylene biosynthesis and high CO₂ inhibits ethylene action (John and Marshal, 1995). Therefore, these conditions are conducive to delay fruit ripening and hence resulted in a longer green-life of fruits. Polyethylene box liners, either sealed or perforated, have been used for several years in the storage of pears and apples. Perforated polyethylene films, are commonly used to minimize weight loss, reduce abrasion damage and delay fruit ripening (Elkashif et al., 2005; Wills et al., 1998). It has been shown that bananas packed in polyethylene -lined boxes have a longer shelf-life than control fruits (Dadzie and Orchard, 1997; Kader, 1992; Mohamoud and Elkashif, 2003). Field handling of bananas combined with placing hands in polyethylene film bags for transport was found to be most suitable technique to reduce wastage of bananas after harvest (Silvis et al., 1976). Smock (1967) showed that ‘Dwarf Cavendish’ bananas could successfully be stored for 7 to 10 days in perforated or sealed bags at ambient temperatures. The sealed bags usually resulted in better keeping quality than perforated
ones. The greatly increased storage-life is attributed to reduction in the rate of natural ethylene production by the bananas and also to reduced sensitivity of the fruit to ethylene (Wills et al., 1998). The gibberellic acid (GA) treatment (100 ppm), either by dipping the tip of the fruit only or the whole fruit, resulted in more delay of fruit ripening and extension of shelf-life of banana fruits. The effect of GA seems to be mainly on colour development, although other aspects of ripening are also affected. GA delayed chlorophyll degradation and fruit softening in banana (Vendrell, 1970) and mango (Khader, 1992), decreased sugar accumulation, TSS and sugar/acid ratio in banana (Ahmed and Tingwa, 1995) and mango (Murthy and Rao, 1982). It has been concluded that fruit ripening can be controlled chemically without lowering the quality of the fruit. The mechanism by which GA retards ripening has not been clearly elucidated, but it may be supposed to act at the gene level, or through modifying the effect of other hormones. Evidence by Valdorino et al. (1967) suggested that GA significantly influenced the level of auxins in plant tissues. Scott and Leopold (1967) reported that GA and ethylene have opposite effect on fruit ripening and senescence. However, unlike auxins, gibberellins did not counteract the stimulatory effect of previously applied ethylene on mango (Singh, et al., 1976). Russo et al. (1968) reported that GA delay in ripening can be overcome by application of ethylene. The delay in fruit ripening and extended shelf-life of banana fruits due to polyethylene film liners and gibberellic acid were reflected in changes in respiration rate, peel color, flesh firmness, total soluble solids and weight loss of the fruits.

2.3.1. Effect on Respiration Rate:

The respiration curves exhibited a typical climacteric pattern, with climacteric peak at 38.2 mg CO₂ / kg-hr in all treatments (Fig.1). The
untreated fruits, kept in carton boxes unlined and untreated with GA reached the climacteric peak after 9 days. The perforated and sealed polyethylene film lining delayed the onset of the climacteric peak by two and three days, respectively, compared to the control fruits (Fig.1). Polyethylene film liners resulted in a modified atmosphere with lower O₂ and higher CO₂ concentrations. Modified atmosphere has been shown to decrease respiration rate and delay the onset of the climacteric peak in banana (Abu-Goukh, 1986; Smock, 1969); mango (Ileperuma and Jayasuriya, 2002; Mohamed and Abu-Goukh, 2003) and tomato (Ahmed and Abu-Goukh, 2003). The effect of modified atmosphere on respiration was attributed mainly to the decrease in O₂ and increase in CO₂ concentrations, reduction in the rate of natural ethylene production and decreased sensitivity of fruits to ethylene (John and Marshal, 1995; Salunkhe and Desai, 1984).

Gibberellic acid (GA) treatment (100 ppm) by dipping only the tip of the fruit or dipping the whole fruit resulted in more delay of the climacteric peak of respiration with the perforated or sealed polyethylene film liners (Fig.1). Banana fruits treated with GA by dipping the fruit tip only or the whole fruit and packed in the perforated film liners reached the climacteric peak four and six days later; while those packed in the sealed film liners reached the climacteric peak five and seven days later, respectively, compared to the untreated fruits. This agrees with previous reports that GA delayed the onset of the climacteric peak in banana (Ahmed and Tingwa, 1995; Awadd et al., 1977) and tomato (Abdel-Khader et al., 1966; Dostal and Leoplod, 1967) and inhibited respiration rate in apple (Lu and Lu, 1992). Lewis et al., (1967) reported that GA had lowered the rate of oxygen uptake in oranges and found that the treated fruits had a lower ratio of monovalent to divalent cations and a higher phosphorus level than the control. They proposed that the integrity of the mitochondrial membranes was affected by GA.
The sealed polyethylene film liners were more effective in delaying the onset of the climacteric peak compared to the perforated ones. That might be due to lower O₂ level and higher CO₂ within the sealed film liners compared to the perforated films. Dipping the whole fruit in aqueous solution of GA
Fig 1: Respiration rate of banana fruits in carton boxes lined with perforated(----) or sealed (—)Polyethylene film untreated with GA(○) or treated with GA by dipping the tip of the fruit (Δ) or dipping the whole fruit (□), compared to control fruits in carton boxes unlined and untreated with GA(●), during storage at 18 ± 2°C and 90-95% RH.
was more effective than dipping only the fruit tip. That might be due to more infiltration of GA into the fruit through the whole fruit peel than through the fruit tip only.

### 2.3.2. Effect on Peel Color:

Peel color score progressively increased during storage of banana fruits (Fig.2). The untreated fruits reached the full yellow stage (color score 7) after 13 Days. The polyethylene film lining, perforated or sealed, delayed the development of peel color by one and two days compared to the control, respectively. Polyethylene film liners resulted in a modified atmosphere and hence delayed peel color development in banana fruits. It has been shown that bananas packed in polyethylene-lined boxes have a longer shelf-life than control fruits (Kader, 1992). Elkashif et al. (2005) found that bananas held in intact polyethylene packages had the longest green-life, followed by those held in perforated ones and unpacked fruits had the shortest. Similar results were reported by Dadzie and Orchard (1997) and Mahmoud and Elkashif (2003).

GA treatment in combination with polyethylene film liners, perforated or sealed, resulted in more delay in peel color development. Bananas treated with 100 ppm GA by dipping the fruit tip or the whole fruit and packed in cartons lined with perforated film liners reached the full yellow color three and five days later, respectively, compared to the untreated fruits. While banana fruits treated with GA (100 ppm) by dipping the tip or the whole fruit and packed the in sealed polyethylene films reached the full yellow color four and six days later, respectively, compared to the control (Fig.2). These results are in agreement with previous reports that GA retarded color development in banana (Ahmed and Tingwa, 1995), orange (Coggins and Eaks, 1967; Coggins and Lewis, 1962) and tomato (Dostal and Leopold, 1967). GA delayed chlorophyll degradation in banana (Vendrell, 1970),
Fig 2: Peel color changes of banana fruits in carton boxes lined with perforated (---) or sealed (—) Polyethylene film untreated with GA (○) or treated with GA by dipping the tip of the fruit (Δ) or dipping the whole fruit (□), compared to control fruits in carton boxes unlined and untreated with GA (●), during storage at 18 ± 2°C and 90-95% RH.
mango (Khader, 1992) and citrus (Greenberg et al., 1987) and inhibited degreening in cultured citrus peel pigments (Garray, 1990). The effect of GA seems to be mainly on color development, although other aspects of ripening processes are affected. Fletcher and Osborne (1965) suggested that GA regulates proteins and nucleic acid synthesis and thus retains the chlorophyll moiety.

The perforated polyethylene film liners was less effective than the sealed ones. That could be due to the ability of the fruits to exchange gases through the perforation, resulting in faster colour development. This in line with previous reports (Dadazie and Orchard, 1997; Elkashif et al., 2005).

2.3.3. Effect on Weight Loss:

Weight loss progressively increased during storage of banana fruits (Fig.3). Weight loss was followed until the fruits reached the full yellow stage (colour score 7). At that stage the control fruits, packed in carton boxes unlined and untreated with GA, reached the highest weight loss percentage of 18% after 14 days. Packing the fruits in carton boxes lined with perforated or sealed polyethylene films reduced the weight loss by 4.5% and 9.1%, respectively, compared to the control fruits. These results were in line with previous reports (Elkashif et al., 2003). Water loss can be reduced effectively by placing additional physical barriers between the produce and the surrounding air (Wills et al., 1998). Packing the produce in intact or perforated polyethylene packages or use of package film liners result in higher relative humidity inside the package and hence reduce weight loss in the produce (Elkashif et al., 2005). Polymeric film packaging has been extensively used to reduce water loss and enhance fruit quality (Purvis, 1983). Elkashif et al. (2005) reported that bananas in intact polyethylene packages had the lowest weight loss, followed by those in perforated ones, whereas the
Fig 3: Weight loss of banana fruits in carton boxes lined with perforated(----) or sealed (——) Polyethylene film untreated with GA(○) or treated with GA by dipping the tip of the fruit (△) or dipping the whole fruit (□), compared to control fruits in carton boxes unlined and untreated with GA(●), during storage at 18 ± 2°C and 90-95% RH.
unpacked fruits had the highest weight loss. These results were consistent with the findings of Elkashif et al. (2003) and Eltayeb (1995). Gibberellic acid treatment in combination with polyethylene lining resulted in more reduction of weight loss. Fruit treatment with GA (100 ppm) by dipping the tip or the whole fruit and packed in perforated film liners reduced weight loss by 12.2% and 20.8%, respectively, compared to the untreated fruits, while those treated with GA (100 ppm) by dipping the tip or the whole fruit and packed in the sealed polyethylene film liners reduced weight loss by 16.0% and 26.7% compared to the control, respectively. The more reduction of weight loss in fruits packed in polyethylene film liners in combination with GA treatment was most probable due to the delay in fruit ripening. During ripening of fleshy fruits changes in tissue permeability and cellular compartmentation occur (Wills et al., 1998). Since ripening was delayed due to GA treatment, tissue permeability would be decreased and reduction in weight loss in the fruit would be obvious.

2.3.4. Changes in Fruit Flesh Firmness:

Fruit flesh firmness progressively declined during storage of banana fruits. The control fruits packed in carton boxes, unlined and untreated with GA reached the final soft stage (0.9 kg/cm²) after 8 days (Fig. 4). Similar drop in flesh firmness was reported in banana (Abu-Goukh et al., 1995), guava (Bashir and Abu- Goukh, 2003), mango (Abu- Goukh and Abu- Sarra, 1993; Mohamed and Abu- Goukh, 2003), tomato (Ali and Abu- Goukh, 2005), pear (Lutton and Holland, 1986), apple, peach and apricot (Salunkhe and Wu, 1973) and date (Barrevelled, 1993)

The polyethylene film lining, perforated or sealed, delayed the drop in flesh firmness during storage of banana fruits. The fruits kept in carton boxes lined with perforated or sealed polyethylene films reached the final soft stage two and four days later, respectively, compared to the control fruits. These
Fig 4: Fruit flesh firmness of banana fruits in carton boxes lined with perforated(----) or sealed ( — ) Polyethylene film untreated with GA(○) or treated with GA by dipping the tip of the fruit (Δ) or dipping the whole fruit (□), compared to control fruits in carton boxes unlined and untreated with GA(●), during storage at 18 ± 2°C and 90-95% RH.
results agree with the findings of Elkashif et al. (2005). Polyethylene film liners result in a modified atmosphere with lower O₂ and higher CO₂ concentrations (Kader, 1992). Modified atmosphere, particularly those containing high CO₂, inhibit the breakdown of pectic substances, so that a firmer texture is retained for a longer period (Wills et al., 1998). It has been shown that bananas packed in polyethylene- lined boxes have a longer shelf-life than control fruits (Dadzie and Orchard, 1997; Kader, 1992; Mahmoud and Elkashif, 2003). Perforated Polyethylene films, are commonly used to minimize weight loss, reduce abrasion damage and delay fruit ripening (Elkashif et al., 2005; Wills et al., 1998). Bananas treated with GA (100 ppm) by dipping the tip of the fruit only or dipping the whole fruit and packed in perforated polyethylene films reached the final soft stage six and ten days later, respectively, compared to the control fruits. While those treated with GA by dipping the tip or the whole fruit and packed in sealed polyethylene films reached the final soft stage eight and twelve days later, compared to the control, respectively (Fig.4). This agrees with previous reports that GA delayed fruit softening in banana (Vendrell, 1970) and mango (Khader, 1992).

2.3.5. Effect on Total Soluble Solids:

Total soluble solids (TSS) progressively increased during storage of banana fruits. Similar increase in total soluble solids was shown during ripening of banana (Abu-Goukh et al., 1995) mango (Mohamed and Abu-Goukh, 2003), guava (Bashir and Abu-Goukh, 2003; Rodriguez et al., 1971) and dates (Dowsan and Aten, 1962). The maximum TSS value reached by the untreated fruits was 20.5% after 10 days(Fig.5). Polyethylene film lining, perforated or sealed, delayed the accumulation of TSS during storage of banana fruits. Bananas kept in carton boxes lined with perforated or sealed
polyethylene films reached the maximum TSS value two and four days later, respectively, compared to the control. Polyethylene film lining result in modified atmosphere conditions which delay fruit ripening (Dadzie and Orchard, 1997; Elkashif et al., 2005; Kader, 1992). John and Marshal (1995) showed that sugars constituted the main component of TSS and resulted from the degradation of starch during ripening of banana fruits. Film lining delays fruit ripening and hence TSS accumulation. The banana fruits treatment with GA either by dipping the tip only or dipping the whole fruit in combination with perforated film liners reached the maximum TSS value six and ten days later, respectively, compared to the untreated fruits. The fruits treated with GA by dipping the tip only or the whole fruit with sealed film liners reached the maximum TSS value eight and twelve days later, respectively, compared to the control (Fig. 5). This is in line with earlier reports that GA decreased sugar accumulation, TSS and sugar/ratio in banana (Ahmed and Tingwa, 1995), mango (Murthy and Rao, 1982) and orange (Lewis et al., 1967).
Fig 5: Total soluble solids of banana fruits in carton boxes lined with perforated(----) or sealed (—)Polyethylene film untreated with GA(○) or treated with GA by dipping the tip of the fruit (Δ) or dipping the whole fruit (□), compared to control fruits in carton boxes unlined and untreated with GA(●), during storage at 18 ± 2°C and 90-95% RH.
Conclusion

The sealed film liners and GA treatment (100 ppm) by dipping the whole fruit were more effective in delaying fruit ripening and extending shelf-life of bananas. That was reflected in more delay in the climacteric peak of respiration, peel color development, TSS accumulation, fruit softening and reduced weight loss during storage.
References


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