Effect of Polyethylene Film Lining and Potassium Permanganate on Quality and Shelf-Life of Banana Fruits

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بسم الله الرحمن الرحيم

DEDICATION

This work is dedicated to my family & all my friends with permanent love.

Abstract

This study was conducted to investigate the effect of using polyethylene film lining, sealed or perforated, and potassium permanganate, in granular form or absorbed in filter paper, 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. The potassium permanganate ($KMnO_4$) in both forms, granules or absorbed in filter paper, resulted in more delay of fruit ripening and extension of shelf-life of banana fruits.

The sealed film liner and $KMnO_4$ in the granular form 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.

ملخص الأطروحة

تم إجراء الدراسة لمعرفة أثر تبطين العبوات بواسطة شرائح البوليثلين المثقب أو غير المثقب و برمنجنات البوتاسيوم ، في صورة حبيبات أو مشبعة في ورق ترشيح على الفترة التخزينية وجودة ثمار الموز.

استخدام شرائح البوليثلين المثقبة أو غير المثقبة أدت إلى تأخير نضج الثمار بصورة واضحة، و إلى الحفاظ على جودة الثمار و إطالة فترتها التخزينية .كما أدت برمنجنات البوتاسيوم في صورة حبيبات أو مشبعة على ورق الترشيح إلى تأخير أكثر لنضج الثمار و إطالة الفترة التخزينية بصورة كبيرة لثمار الموز.

أوضحت التجارب أن استخدام تبطين العبوات بشرائح البوليثلين غير المثقبة و برمنجنات البوتاسيوم في صورة حبيبات كانت أكثر فعالية في إطالة الفترة التخزينية و المحافظة على جودة ثمار الموز. انعكس ذلك في تأخير الذروة التنفسية و تأخير التحول في لون القشرة الخارجية و تراكم المواد الصلبة الذائبة الكلية و ليونة الثمار و نقصان نسبة فقد الوزن أثناء تخزين ثمار الموز.

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Chapter One

Literature Review

1.1. Origin, Importance and World Production:

Banana (*Musa* spp.) belongs to the genus Musa of the family Musaceae. Its origin appears to be Southeast Asia, with Eastern Malaysia and the Philippine in particular, considered the primary indigenous origin (Simmonds, 1966). Now it has spread all over the tropical world with the largest production centered in Africa. It is a fruit of high nutritional value and a good source of vitamins A, B_1, B_2, C, minerals and calories (Salunkhe and Desai, 1984). Bananas are the main fruit in international trade and the most popular one in the world. They are the first exported fruit, in terms of volume and rank second after citrus fruits in terms of value. Bananas are also a very important stable commodity for many developing countries. Some of the main producing countries are India, Brazil, Ecuador and china, whereas the four leading banana exporter countries are Ecuador, Costa Rica, Philippines and Colombia (FAO, 2004). The world production increased from 64.6 million metric tons in 1999 to 71.3 million metric tons in 2004 (FAO, 2004).

In Sudan, banana is the most widely consumed fruit due to taste and price reasons. Large quantities of good quality bananas are produced for local market. The harvested area increased only slightly from 2,200 ha in 2000 to 2,300 in 2004, while the production increased from 72,000 tons in 2000 to 74,000 tons in 2004 (FAO, 2004).

1.2. Fruit Ripening:

Fruit ripening was defined as the terminal period of maturation during which the fruit attains full development and its maximum aesthetic and edible quality (Gortner *et al.*, 1967). Biale and Barcus (1970) describes ripening as the process which involves chemical transformations resulting in development of texture, flavor, aroma and color, desirable in fruits used for human consumption. Ripening is a dramatic event in the life of a fruit. It transforms a physiologically mature but inedible plant organ into a visually attractive olfactory and taste sensation. Ripening marks the completion of development of a fruit and the commencement of senescence, and it is normally an irreversible event (Wills *et al*., 1998).

Ripening is the result of a complex of changes, many of them probably occurring independently of one another. The number, complexity and commercial importance of these changes make fruit ripening special case of plant organ senescence. Normally ripening will occur at the proper physiological stage, indicating that there are internal control systems which operate to prevent premature ripening and thus insure that the event occurs at the proper stage of ontogeny (Looney, 1972). Certainly the most significant changes during ripening are those that make the fruit palatable, thus appealing to both taste and flavor (Tingwa, 1974). From an economic stand point, textural change is the most crucial of all, as it directly affects the shelf-life of the fruit and its keeping quality (Tucker and Grierson, 1987).

Bananas, like other climacteric fruits, are characterized by a sudden burst of respiration, followed by internal metabolic changes. The fruit undergoes significant textural and color transformation as it passes through the ripening process. The crisp, hard and dark green banana fruit turns into yellowish with tender and soft internal pulp (Ramaswamy and Tung, 1989). Bananas are picked at mature-green stage and are never allowed to ripen on plant, in order to avoid the splits of the peel; also the fruit would have poor texture. Therefore, ripening is initiated by either the natural evolution of endogenous ethylene as the fruits reach full maturity, or commercially by using exogenous ethylene (Marriott, 1980).

Ethylene gas (C_2H_4) is a natural plant hormone produced by many horticultural commodities (Reid, 1992). It has been clearly established that all fruits produce minute quantities of ethylene during ripening; however, climacteric fruits produce much larger amounts of ethylene during ripening than non-climacteric fruits (Wills *et al.,* 1998). For climacteric fruits, like banana, the role of ethylene is to coordinate ripening (Burg and Burg, 1965) and it is produced in relatively high amounts. It accelerates fruit senescence and markedly shortens its storage life. It enhances chlorophyll degradation respiration, fruit softening, ripening and senescence (Kader, 1992).

1.3. Respiration Rate:-

Respiration is the process by which stored organic materials in the fruit, mainly simple acids and sugars, are broken down into simple end products, CO_2 and H_2O, with O_2 consumption and energy release. Respiration rate is an excellent indicator for metabolic activity of the tissue and thus is a useful guide to the potential storage life of fresh fruits and vegetables (Wills *et al*., 1998). The respiration rate is inversely proportional to the shelf-life of the product; a higher rate decreases shelf-life (Day, 1993). Biale (1960) found that the stage of ripeness corresponded closely with the climacteric peak in fruits such as banana, tomato and mango. At first, unripe fruit produces ethylene at constant but low rates. Then ethylene production rises dramatically and respiration increases (Biale *et al*., 1954).

Krishnamurthy *et al*. (1960) classified respiration of mango fruits into four distinct phases on the observed changes: (1) Pre-climacteric phase, when the fruit is green and firm and CO_2 production is at minimum. (2) A climacteric rise, when a sudden increase in CO_2 production is observed and fruit remains green and firm. (3) A climacteric peak, marked by a peak in CO_2

production, during this stage the fruit tends to break in color, becomes softer and develops an aroma characteristic of the variety. (4) Post-climacteric phase, when the CO_2 released shows a sudden decline and the fruit develops attractive color and aroma and becomes soft and edible ripe. John and Marchal, (1995) stated three main events that occur after the harvest of banana fruits: (1) The pre-climacteric phase, where the fruit remains unripe; (2) The ripening phase, where respiration rate is high; and,(3) The senescent phase, when quality starts to deteriorate. This climacteric behavior helps to determine 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 the longest pre-climacteric period is desired.

1.4. Compositional Changes:

The ripening fruit undergoes many physio-chemical changes after harvest that determines the quality of the fruit purchased by the consumer. 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 accepted as human food (Mattoo *et al*., 1975). Normal ripening of fruits involves a series of apparently unrelated biochemical reactions that are switched on and coordinated during the climacteric period (Grierson and Kader, 1986). These changes alter both the taste and texture of the produce (Wills *et al.,* 1998). Some of these changes are described in the text below.

1.4.1. Color Changes:

Color is the most obvious change that occurs in many fruits and is often the major criterion used by consumers to determine whether the fruit is ripe or unripe (Kays, 1999). The most common change is the loss of green color which is due to the disappearance of chlorophyll. The total chlorophyll of green banana decreases in the peel during ripening (Desai and Deshpande, 1975) and chlorophyllase activity increases sharply at the onset of the climacteric (Looney and Patterson, 1967). Yellowing in bananas begins shortly after the climacteric peak and the fruit becomes full yellow within three to seven days at normal ripening temperature (Palmer, 1971). The loss of green color is due to 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 chlorophllase activity. Loss of green color depends on one or all of these factors acting in sequence to destroy the chlorophyll structure (Wills *et al.*, 1998).

The disappearance of chlorophyll is often associated with the synthesis and /or revelation of pigments. In bananas the carotenoids are synthesized during the developmental stages on the plant, but remain masked by the presence of chlorophyll. Following the degradation of chlorophyll, the yellow caretenoid pigments become visible (Wills *et al.*, 1998).

Color changes in ripening fruit have been associated by the consumer with the conversion of starch to sugar (i.e. sweetening) and the development of other 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 fruit such as bananas are ripened at higher than optimum temperatures, 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 bananas, pears, apples and tomatoes. The fruits are classified according to the peel color by visually matching the peel color of the fruit against the color chart (Wills *et al*., 1998). Kader (1992) stated that the color of the peel is used as an indictor of banana fruit ripening. A scale of 1 to 7 is used; where 1 is dark green, 2 is light green, 3 is more green than yellow, 4 is more yellow than green, 5 is yellow with green tips, 6 is fully yellow, and 7 is yellow flecked with brown. Objective measurement of color is possible using a variety of light reflection or transmission spectrophotometers. The Hunter and Minolta color / color difference meters, which measure surface color, are widely used in research work (Wills *et al*., 1998).

Stover and Simmonds (1987) stated that the peel color is well correlated with the starch-sugar ratio. So depending upon the peel color and carbohydrate correlation standers for ripening classes of banana include the following: 1, green, the fruit is hard, rigid, no ripening occurred; 2, green with trace of yellow, ripening started; 3, more green than yellow; 4, more yellow than green; 5, yellow with green tip; 6, full yellow, the fruit peels readily, firm ripe; 7, yellow lightly flecked with brown, the fruit is fully ripe and aromatic; 8, yellow with increasing brown areas, the fruit is overripe, pulp very soft and darkening, highly aromatic (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). Pulp firmness is often inversely related to ripening, implying that, as ripening progressed, pulp firmness declined (Smith *et al*., 1990). Loss of firmness or softening during ripening has been associated with two processes; the first, is the breakdown of starch to form sugar; and the second, is the breakdown of the cell walls or reduction in the middle lamella cohesion due to solubilisation of pectic substances (Ali and Abu-Goukh, 2005; Palmer, 1971; Smith *et al*., 1990). 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, 1979). From a horticultural perspective, tissue firmness is an important quality attribute and the rate of firmness loss during ripening may influence not only fruit quality but also its storage life.

Fruits undergo progress decline in flesh firmness with fruit 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 and coincided with the climacteric peak of respiration. Similar pattern of change was reported for mango (Abu-Goukh and Abu-Sarra, 1993; Mohamed and Abu-Goukh, 2003), guava (Abu-Goukh and Bashir, 2003), tomato (Ali and Abu-Goukh, 2005), pear (Luton and Holland, 1986), apples, peaches, and apricots (Salunkhe and Wu, 1973).

The mechanisms by which fruits soften during ripening remain unclear and are subject to much speculation. Although turgor loss and starch degradation and subsequent decline in its content during ripening might contribute, however, enzyme-catalyzed changes to wall structure and composition are considered the major factor of softening of fruits (Hall, 1986). Respect to the non-structural carbohydrates, mature fruits of banana and mango contain as high as 20-25% on fresh weight basis of starch, while guava, papaya, contain either very little or no discernible amounts of starch. Although starch content differed markedly with the fruit type, these differences are not always reflected in their firmness levels at maturity or their softening rates during ripening (Lazan and Ali, 1993; Seymour *et al*., 1993).

Fruit softening characterized by reduction in fruit firmness is reported to be associated with the breakdown of pectic substances and hemi-celluloses in the middle lamella, which weakens cell walls and reduces the cohesive forces binding cells together (Wills *et al*., 1998).

Fruit softening during ripening is frequently attributed to the enzymatic degradation of cell wall materials (Ahmed and Labavitch, 1980; Ali and Abu-Goukh, 2005). Polygalacturonase (PG) and cellulase activity progressively increase during fruit 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) and tomato (Ali and Abu-Goukh, 2005).

The current theory is that PE removes the methyl groups of the galacturonic acid polymer (Lee and MacMillan, 1970), which then enables PG to depolymerise the de-esterified polygalacturonoid chain and reduces its molecular weight (Benkova and Markovic, 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 lyases in fruit softening. Pectate layses (PL) catalyse the Ca^{+2}- dependent cleavage of de-esterified pectin, which is a major component in the primary cell walls 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 PL, 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 fruits is 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 those fruits whose major carbohydrate pool is sugars (Kader, 1992). Unripe banana is mainly composed of starch, which represents 20-25% of the fresh weight of pulp

(Seymour, 1993). 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.,*1970). Total soluble solids were reported to increase during fruit ripening in banana (Abu-Goukh *et al.,*1995), mango (Abu-Goukh and Abu-Sarra, 1993; Mohamed and Abu-Goukh, 2003) guava (Bashir and Abu-Goukh, 2003) and tomato (Ahmed and Abu-Goukh, 2003). The increase in TSS was attributed to the hydrolysis of starch into sugars as the fruit ripens (Popenoe *et al*., 1958; Biale, 1960). This conversion was reported to be the most important change in ripening bananas (Stover and Simmonds, 1987). The increase in sugar renders the fruit much sweeter and therefore more acceptable. Afterwards, total sugar content does not change significantly during the later stage of ripening. The break down of starch and synthesis of sugar is usually completed at full ripeness, the fruit then contains about 1% starch and 23% sugar (Marriott *et al*., 1981).

1.5. Water Loss:

Weight loss is mainly attributed to water loss and most fruits are usually subjected to this phenomenon during post-harvest handling and transportation. Water loss is a main cause of deterioration because it results not only in direct quantitative losses (loss of weight), but also in qualitative losses such as losses in appearance (shriveling), textural and nutritional quality. Moisture content of most fruits is high, and weight loss 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 shriveled, and this happen 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 per cent. The necessity for controlling humidity in banana ripening rooms is generally well recognized.

The amount of weight loss during storage is influenced by internal commodity factors, such as morphological and anatomical characteristics, surface-to-volume ratio, surface injuries and maturity stage; and external or environmental factors such as temperature, relative humidity, air movement and atmospheric pressure inside the storage facility (Ben-Yehoshua *et al*., 1979). 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 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 films (Wills *et al.,* 1998). Water loss can be reduced effectively by placing additional physical barriers 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 tarpaulins. Materials such as polyethylene films are excellent vapor barriers since their rate of water transfer is low compared with that of paper and fiberboard, which have a high permeability to water vapor. The use of very thin plastic wrap and heat-shrink films for packaging individual fruits is 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 results in high 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 to enhance fruit quality (Eltayeb, 1995; Purvis, 1983).

1.6. Control of Fruit Ripening:

The use of ethylene for hastening ripening of fruits dates back to antiquity and many examples have been cited (Kader ,1992). In the recent times, the discovery of the hormonal nature of ethylene was associated with the discovery that ethylene would ripen fruits, and the observation that ripe fruits would cause ripening of other fruits. Now ethylene is considered as the natural ageing and ripening hormone (Kader, 1992).

Synthetic ethylene applied to fruits can cause a great burst of natural ethylene production. The concentration of ethylene required for ripening various fruits vary, but in most cases are in the range of 0.1 to 1.0 ppm. It can be applied from gas cylinders, ethylene generators, ethylene releasing chemicals or related analogues (Kader, 1992). The effectiveness of ethylene in achieving faster and more uniform ripening depends on maturity stage, temperature and relative humidity of the ripening room, ethylene concentration and duration of the exposure to ethylene. In general, optimum ripening conditions for fruits are: temperature of 18-25°C, relative humidity of 90-95%, ethylene concentration of 10-100 ppm for 24-72 hours, air circulation sufficient to ensure distribution of ethylene within the ripening room and adequate air exchange to prevent accumulation of CO_2 which reduces the effectiveness of ethylene.

Control of fruit ripening, initiation or delay, will depend 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 ripen just before marketing (Wills *et al.*, 1998). Therefore the action of ethylene must be avoided during storage and transport in order to prevent premature ripening.

Attainment of maximum possible storage life is the goal of storage studies. Usually, combinations of treatments are restored to. Thus waxing, polyethylene box lining, low O_2, high CO_2 and ripening inhibitors are sometimes combined to prolong storage life. However, even with the optimum treatments of each for ripening inhibition, endogenous ethylene is always a problem. Delay of fruit ripening and prolong shelf-life can be achieved by one or more of the following:

1.6.1. Low Temperature:

In climacteric fruits, low temperature can be used to achieve a delay in the onset of ripening. Lowering the temperature not only reduces the production of ethylene, but also the rate of response of the tissue to ethylene (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. It was clearly demonstrated that endogenous levels of ethylene in fruits held in hypobaric storage were greatly reduced, and that the longer storage life obtained in such systems could be reduced by adding ethylene to the atmosphere (Burg and Burg, 1966; Kader, 1992). Alpelbaum *et al.* (1977) found that the slowing of banana ripening is inversely related to atmospheric pressure of storage. Abu-Goukh (1986) reported that ethylene production and respiration activity of bananas held at 20ºC in gas mixture of 1 to 10% O_2 under one fifth atmospheric pressure were considerably depressed, no climacteric was apparent and fruits 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 after being transferred to air.

1.6.3. Inhibition of the Effects of Ethylene:

Delaying of fruit ripening can be achieved by modified or controlled atmosphere storage. The primary effects of controlling the concentrations of oxygen and of carbon dioxide in the storage atmosphere are thought to be reduction in the rate of respiration and associated processes. Reduction of the partial pressure of O_2 and elevation of the partial pressure of CO_2 can reduce the rate of natural ethylene produced by the fruit and decrease the sensitivity of the fruit to ethylene action. Carbon dioxide is known as a competitive inhibitor of ethylene action (Wills *et al.*, 1998).

The use of plastic films to achieve modified atmosphere is increasing, not only in packaging but also in controlled atmosphere construction. Polyethylene box liners, either sealed or perforated, have been used for several years in the storage of pears and apples, but only to a limited extend 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' bananas could successfully be stored for seven to ten days in perforated and 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 a reduction in the rate of natural ethylene production by the bananas and also to a reduced sensitivity of the fruits to ethylene (Wills *et al.*, 1998).

1.6.4. Chemical Removal of Ethylene:

Ethylene can be removed by a number of chemical processes. This is mainly by oxidizing it to carbon dioxide and water. Potassium permanganate ($KMnO_4$) is an oxidizing agent quite effective in reducing ethylene levels. Since $KMnO_4$ is non-volatile, it can physically be separated from the produce, thus eliminating the risk of chemical injury (Wills *et al.*, 1998). $KMnO_4$ is a chemical which has long been used to remove ethylene from the storage atmosphere (Salunkhe and Desai, 1984).

Commercial materials utilize the ability of KMnO4 to oxidize ethylene to CO_2 and water is being used. The requirements for such materials are a high surface area coated with the permanganate, and ready permeability to gases. Many porous materials have been used to manufacture permanganate absorbers, including vermiculite, pumice and brick. The type of material utilized may depend on the purpose for which the absorber is required (Kader, 1992). A commercial preparation of this absorbent is called "Purafil" (alkaline $KMnO_4$ on silicate carrier), produced by Mabson Chemical Co., proved effective in the complete absorption of ethylene (Lui, 1970). Smock (1970) observed that "Purafil" has proven useful for reducing ethylene in cartons during storage and transit.

Ethylene which developed in storage chambers had to be removed to get extended storage life, otherwise endogenous ethylene over powered the low O_2 effect (Smock, 1967). Removal of ethylene gas can have an additional benefit on extending green life of bananas, under both ambient and modified atmosphere conditions (Scott *et al*., 1970; Liu, 1976; Abu-Goukh, 1986). The use of $KMnO_4$ 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). The high carbon dioxide and low oxygen atmosphere generated within the sealed bags decreases the response by the fruits to ethylene and hence retards ripening. The addition of $KMnO_4$ further retards ripening by maintaining ethylene at a low level for a long period. This technique has also been successfully demonstrated to delay the ripening of whole bunches of bananas during shipment (Wills *et al*., 1998). It was estimated that about two weeks additional storage life was obtained by packing $KMnO_4$ with the fruits (Salunkhe and Desai, 1984). It has been shown that bananas packed in polyethylene- lined boxes could be transported at higher ambient temperatures in the presence of $KMnO_4$ absorber (Kader, 1992).

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 laboratory, since potassium permanganate absorbers are cheaper and more widely available (Kader, 1992).

Silver ions applied in aqueous solution as $AgNO_3$ 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.

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Chapter two

Effect of Polyethylene Film Lining and Potassium Permanganate on Quality and Shelf-Life of Banana Fruits.

2.1. Introduction

Banana (*Musa* spp.), belongs to the family Musaceae, is one of the most important fruit crops grown and consumed worldwide. It is grown in more than 100 countries, mainly in sub-tropical areas ranking third place in the world fruit volume production after citrus and grapes (Stover and Simmonds, 1987). Annual world production of bananas is 71.3 million metric tons (FAO, 2004). The leading producing countries are: Brazil, India, Uganda and Nigeria.

In Sudan, banana is very popular for its nutritive value, low price and availability all the year round. It is grown almost in every state; with total annual production of about 74 thousand metric tons (FAO, 2004).

Banana is a typical climacteric fruit that exhibits characteristic rise in ethylene production and respiration rate during ripening (Stover and Simmonds,1987). The high rate of respiration which is usually associated with short shelf-life, soft texture and high moisture content makes banana a very perishable fruit that requires absolute care during handling and transportation. Therefore, proper handling techniques, reduction of post-harvest losses, delaying of fruit ripening and extending the shelf-life are crucial for the development of a sound banana industry in the Sudan.

Polyethylene films, sealed or perforated, are commonly used to minimize weight loss and reduce abrasion damage. The use of plastic films to achieve modified atmosphere is increasing, not only in packaging, but also in controlled store construction. Polyethylene box liners, either sealed or unsealed, have been used for several years in the storage of pears and apples (Wills *et al*., 1998).

Potassium permanganate ($KMnO_4$) is quite effective in reducing ethylene levels by oxidizing it to carbon dioxide and water. It was demonstrated that $KMnO_4$ retarded the ripening of many fruits (Wills *et al*., 1998). Scott *et al*. (1970) found that the storage life of bananas in sealed polyethylene bags containing $KMnO_4$ was extended by two weeks, compared to the control. "Purafil" which is a commercial preparation of alkaline $KMnO_4$ on a silicate carrier, proved effective in complete absorption of ethylene from bananas held in sealed polyethylene bags (Liu, 1970). Abu-Goukh (1986) reported that "Purafil" had reduced respiration rate, decreased ethylene production and delayed banana fruit ripening.

This study was carried out to investigate the effect of polyethylene film lining and potassium permanganate on quality and shelf-life of banana fruits.

2.2. Materials and Methods

2.2.1. Experimental Material:

"Dwarf Cavendish" banana fruits were obtained from a private orchard in Shambat area, Khartoum North (15° 40′ N, 32° 32′E). 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 10% Clorox (52g/Cl/l) as a disinfectant and air dried.

2.2.2. Fruit Treatment:

The fruits were distributed among the seven treatments (50 fruits each) in a randomized complete block design with three replications. The fruits were packed in carton boxes lined with either sealed (unperforated) or perforated polyethylene films (0.0015mm) or left without lining as control. Potassium permanganate ($KMnO_4$) was used in two forms: (1) Half a gram of pure $KMnO_4$ granules in small mesh bags, (2) Half a gram of $KMnO_4$ dissolved in a small amount of distilled water and absorbed in a 10-cm filter paper to increase the contact surface of $KMnO_4$ with the surroundings.

Three boxes in each replication were lined with sealed polyethylene films and three with perforated ones. In one box of each type of polyethylene lining, $KMnO_4$ was used as granules in a mesh bag, in the other $KMnO_4$ absorbed in filter paper was used and in the third no $KMnO_4$ was used. All the boxes were stored at 18± 2°C and 90-95% relative humidity.

2.2.3. Parameters:

2.2.3.1. 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 CO_2/ kg-hr.

2.2.3.2. 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 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.

2.2.3.3. 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 (%) in fruits was calculated according to the formula: $W_1 = [(W_0 - W_t) / W_0] \times 100\ \%$; 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.

2.2.3.4.. Flesh Firmness:

Flesh firmness was measured 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 an 8mm diameter plunger tip was used. Two readings were taken from opposite side of each fruit after the peel was removed. Flesh firmness was expressed in kilograms per square centimeter.

2.2.3.5. Total Soluble Solids:

Total soluble solids (TSS) were measured directly from the fruit pulp in the fruits used for flesh firmness at two day intervals during storage, using Kruss hand refractometer (Mode HRN-32) and was expressed as percentage.

2.2.4. 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 process of respiration of fruit packed in polyethylene film resulted in a modified atmosphere with lower O_2 and higher CO_2 concentrations. Low O_2 concentration suppresses ethylene biosyntheses and high CO_2 inhibits ethylene action (John and Marchal, 1995). Therefore, these conditions are conducive to delay fruit ripening and hence resulted in a longer green-life of fruits. 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.

Polyethylene box liner, either sealed or perforated, has 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; Mahmoud 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 potassium permanganate ($KMnO_4$) in both forms, granules or absorbed in filter paper, resulted in more delay of fruit ripening and extension of shelf-life of banana fruits. $KMnO_4$ is an oxidizing agent quite effective in reducing ethylene levels by oxidizing it to carbon dioxide and water (Kader, 1992). $KMnO_4$ is a chemical which has long been used to remove ethylene from the storage atmosphere (Salunkhe and Desai, 1984). Removal of ethylene gas can have an additional benefit on extending green-life of bananas, under both ambient and modified atmosphere conditions (Scott *et al*, 1970; Liu, 1976; Abu-Goukh, 1986).

The use of $KMnO_4$ 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). The high CO_2 and low O_2 atmosphere generated within the sealed bags decreases the response by the fruit to ethylene and hence retards ripening. The addition of $KMnO_4$ further retards ripening by maintaining ethylene at a low level for a long period. This technique has also been successfully demonstrated to delay ripening of whole bunches of bananas during shipment (Wills *et al*, 1998). It was estimated that about two weeks additional storage-life was obtained by packing $KMnO_4$ with the fruits (Salunkhe and Desai, 1984). It has been shown that bananas packed in polyethylene-lined boxes could be transported at higher ambient temperatures in the presence of $KMnO_4$ absorber (Kader, 1992).

The delay in fruit ripening and extended shelf-life of banana fruits due to polyethylene film liners and potassium permanganate 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 32.5 mg CO_2/ kg-hr in all treatments (fig.1). The untreated fruits, kept in carton boxes unlined and without $KMnO_4$, reached the climacteric peak after 8 days. The perforated polyethylene film lining delayed the onset of the climacteric peak by two and four days respectively, compared to the control fruits (fig.1). Polyethylene film liners resulted in a modified atmosphere with lower O_2 and higher CO_2 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 (Illeperuma 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 decrease in O_2 and increase in CO_2 concentrations, reduction in the rate of natural ethylene production and the decreased sensitivity of fruits to ethylene (John and Marchal, 1995; Salunkhe and Desai, 1984).

$KMnO_4$ in both forms absorbed in filter paper or granules resulted in more delay of the climacteric peak of respiration with the perforated or sealed polyethylene film liners (Fig.1). Banana fruits packed in the perforated film liners with $KMnO_4$ in filter papers or granules in small mesh bags reached the climacteric peak 6 and 8 days later; while those packed in sealed film liners with $KMnO_4$ in filter paper or granules reached the climacteric peak 10 and 12 days later compared to untreated fruits, respectively. These results agree with previous reports that $KMnO_4$ delayed the onset of the climacteric peak in banana (Abu-Goukh, 1986; Scott *et al.*, 1970), papaya (Corrêa *et al.*, 2005) and apricot (Paluo and Crisosto, 2003).

The use of $KMnO_4$ in conjunction with modified atmosphere storage in polyethylene bags was found to delay the onset of the climacteric peak and to retard ripening of bananas (Scott *et al.*, 1970). The high CO_2 and low O_2 generated within the sealed bags decreased the response by the fruit to ethylene. The addition of $KMnO_4$ further decreases respiration and delays

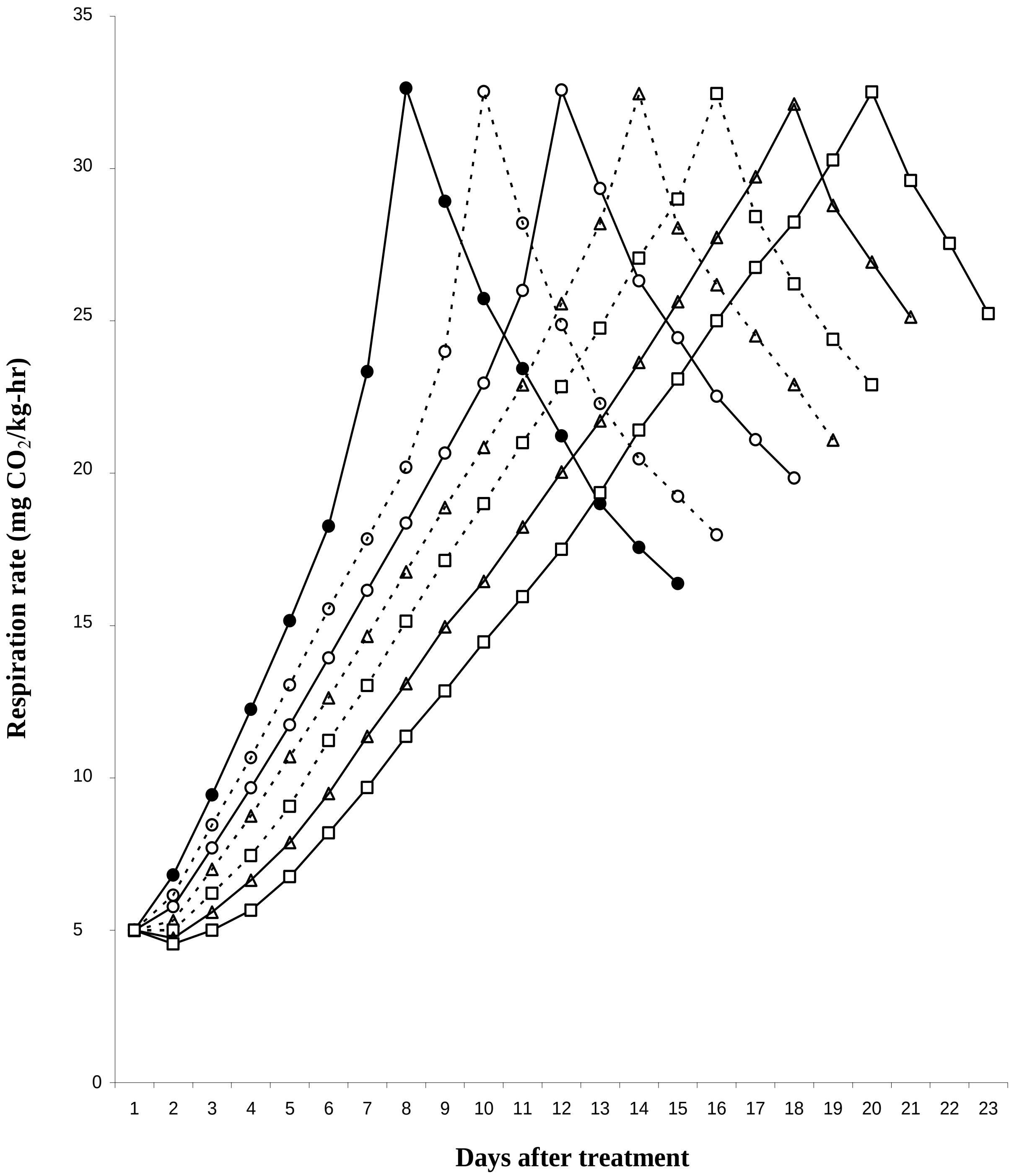

Fig.1: Respiration rate of banana fruits in carton boxes lined with perforated (----) or sealed (——) polyethylene films without $KMnO_4$ (o) or with KMnO4 absorbed in filter paper (Δ) or $KMnO_4$ granules (□), compared to control fruits in carton boxes unlined and without $KMnO_4$ (●), during storage at 18± 2˚C and 90-95% RH.

ripening by maintaining ethylene at a low level for a long period (Wills *et al.,*1998).

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 O_2 level, higher CO_2 and less ethylene within the sealed film liners compared to the perforated films.

Potassium permanganate in the granular form was more effective in decreasing respiration and delaying the climacteric peak. That might be due to less $KMnO_4$ absorbed in the filter paper during the preparation process or the wetting and drying might negatively affect the oxidizing property of the material.

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 14 days. The polyethylene film lining, perforated or sealed, delayed the development of peel color by one and two days compared to the control, respectively (Fig.2). 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 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. Similar results were reported by Dadzie and Orchard (1997) and Mahmoud and Elkashif (2003).

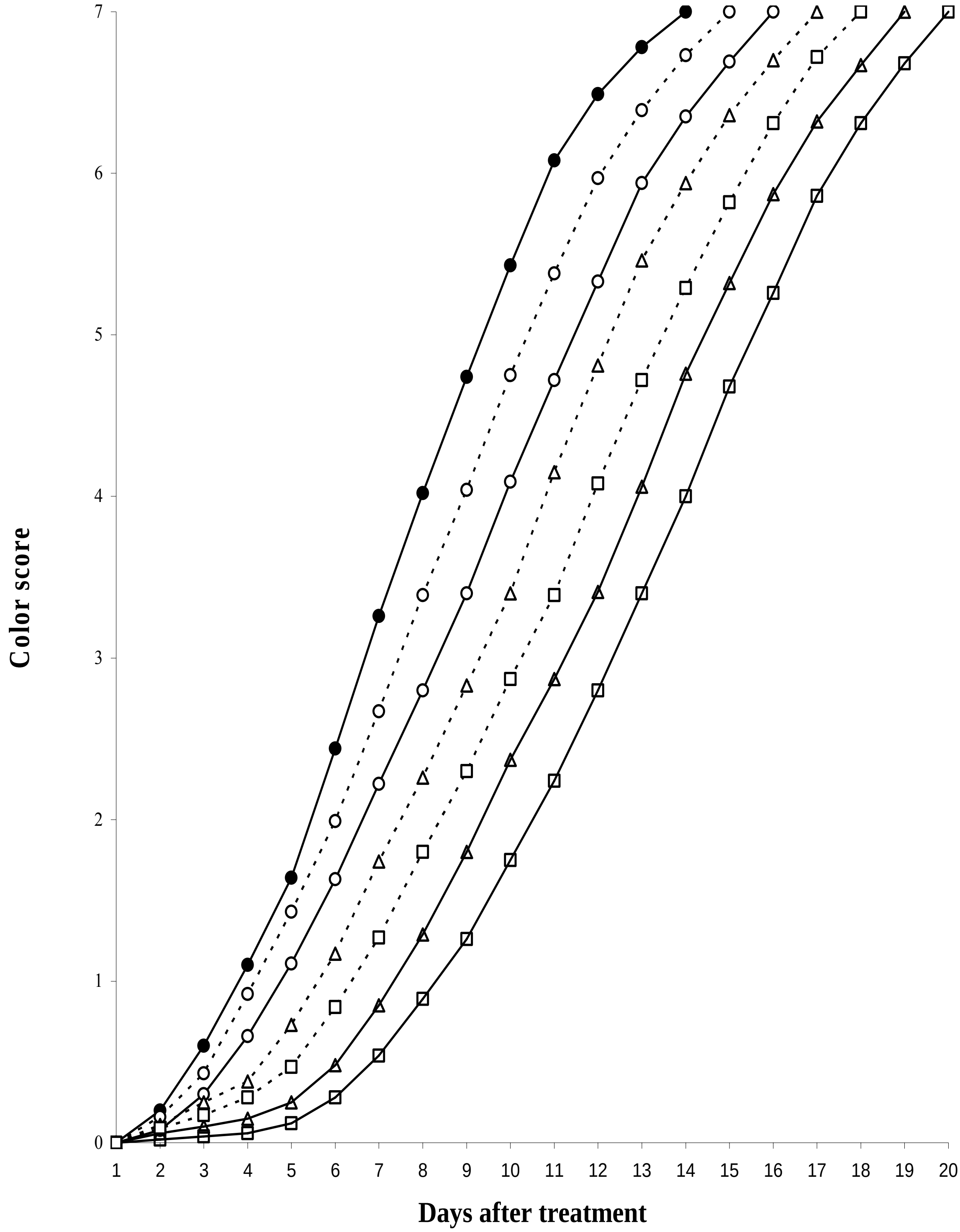

Fig.2: Peel color changes of banana fruits in carton boxes lined with perforated (---) or sealed (—) polyethylene films without KMnO4 (o) or with KMnO4 absorbed in filter paper (Δ) or KMnO4 granules (□), compared to control fruits in carton boxes unlined and without KMnO4 (●), during storage at 18± 2˚C and 90-95% RH.

$KMnO_4$ treatment, in both forms in combination with perforated or sealed polyethylene lining resulted in more delay in peel color development. Bananas packed in cartons lined with perforated film liners with $KMnO_4$ absorbed in filter papers or granules in mesh bags reached the full yellow stage three and four days later, respectively, compared to the untreated fruits, while banana fruits with $KMnO_4$ in filter paper or granules packed in sealed polyethylene films reached the full yellow stage five and six days later, compared to the untreated fruits, respectively (Fig.2). The removal of endogenous ethylene by $KMnO_4$ was an additional benefit for extending green-life of bananas under both ambient and modified atmosphere conditions (Scott *et al.,* 1970; Liu, 1976; Abu-Goukh, 1986). The use of $KMnO_4$ in conjunction with modified atmosphere storage was reported to delay color development in bananas (Abu-Goukh, 1986; Scott *et al.,* 1970) and papaya (Corrêa *et al.*, 2005). 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 color development. This is 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 (color score 7). At that stage the control fruits, packed in carton boxes unlined and without $KMnO_4$, reached the highest weight loss percentage of 25.8% after 14 days. Packing the fruits in carton boxes lined with perforated or sealed polyethylene films reduced the weight loss by 5.0% and 10.1% respectively, compared to the control fruits. These results were in line with previous reports (Elkashif *et al.,* 2005; Mahmoud and Elkashif*.,* 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 film lining results in higher relative humidity inside the package and hence reduces weight loss in the produce (Elkashif *et al.,* 2005; Golomb *et al.,* 1984). Polymeric film packaging has been extensively used to reduce water loss and to 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 unpacked fruits had the highest weight loss. These results were consistent with the findings of Mahmoud and Elkashif (2003) and Eltayeb (1995). $KMnO_4$ in both forms with polyethylene lining resulted in more reduction of weight loss. The perforated film liners with $KMnO_4$ absorbed in filter paper or granules in mesh bags, reduced weight loss by 14.7% and 20.2%, respectively, compared to the control while the sealed film liners with $KMnO_4$ in filter paper or granules reduced weight loss in fruits by 25.2% and 31.4% compared to the control fruits, respectively (Fig.3). The more reduction of weight loss in fruits packed in polyethylene liners with conjunction of $KMnO_4$ could be due to the delay in the fruit ripening in the presence of $KMnO_4$ as described earlier. During ripening of fleshy fruits changes in tissue permeability and cellular compartmentation occur (Wills *et al.,* 1998). Since ripening was delayed in the presence of $KMnO_4$, tissue permeability would be decreased and reduction in weight loss in the fruits would be obvious.

2.3.4. Effect on Flesh Firmness:

Fruit flesh firmness progressively declined during storage of banana fruits. The control fruits packed in carton boxes, unlined and without $KMnO_4$ reached the final soft stage (0.8 kg/cm^2) after 10 days (fig.4). 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

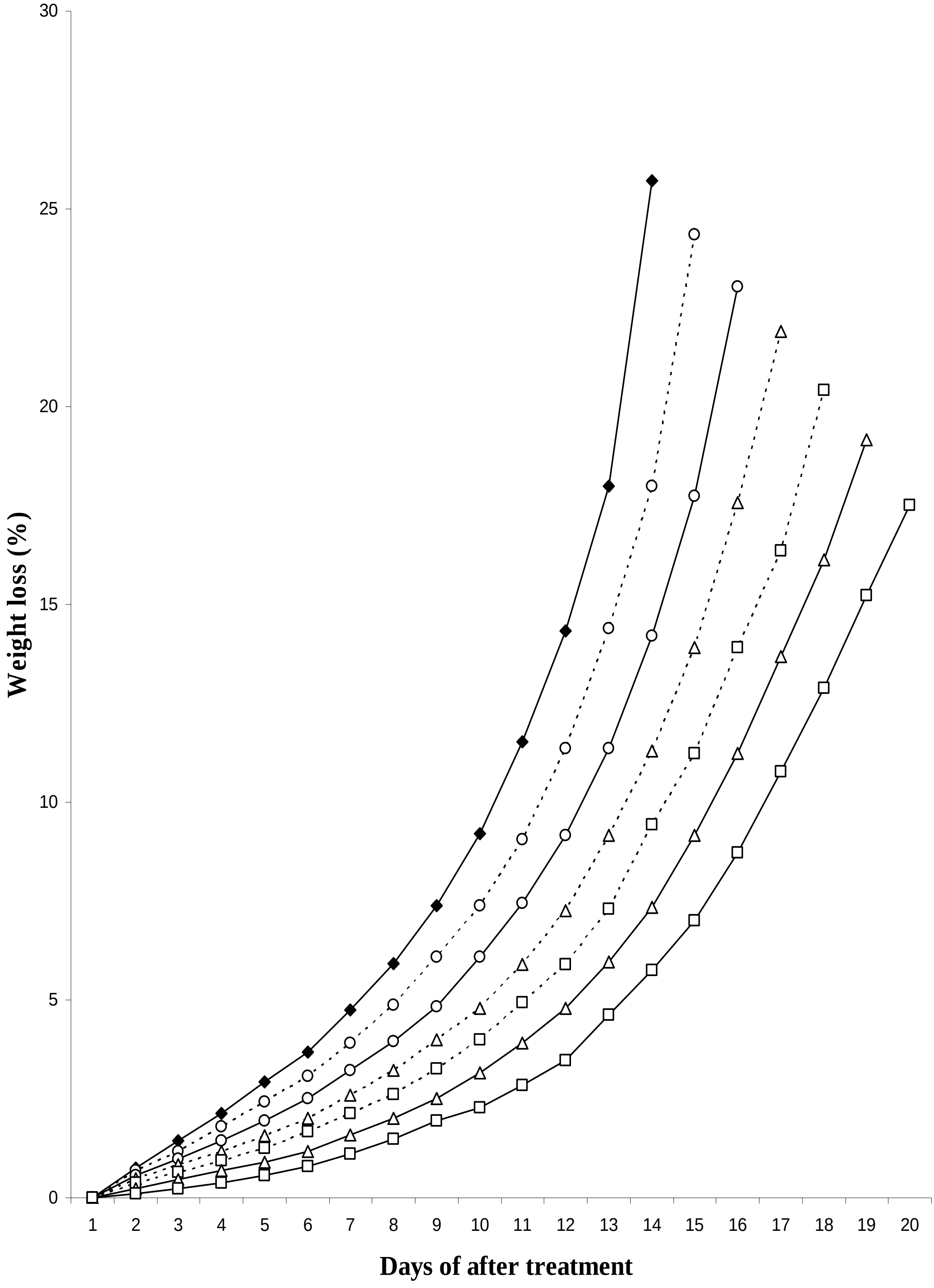

Fig. 3:Weight loss changes of banana fruits in carton boxes lined with perforated (----) or sealed (—) polyethylene films without KMnO4 (o) or with KMnO4 absorbed in filter paper (Δ) or KMnO4 granules (□), compared to control fruits in carton boxes unlined and without KMnO4 (■), during storage at 18± 2˚C and 90-95% RH.

with perforated or sealed polyethylene films alone reached the final soft stage two and four days later, respectively, compared to the control fruits. These results agree with the finding of Elkashif *et al.*(2005). Polyethylene film liners result in a modified atmosphere with lower O_2 and higher CO_2 concentrations (Kader, 1992). Modified atmospheres, particularly those containing high CO_2, inhibit the breakdown of pectic substance, 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).

$KMnO_4$ absorbed in filter paper or granules in combination with perforated polyethylene lining reached the final soft stage six and eight days later, respectively, compared to the control fruits. While $KMnO_4$ in filter paper or granules with sealed polyethylene films reached the final soft stage eight and ten days later, compared to control, respectively (Fig.4). This agrees with previous reports that $KMnO_4$ combined with sealed polyethylene film lining was more effective in delaying fruit flesh softening in mango (Castro et *al*., 2005) and avocado fruits (Joyce et *al*., 1995).

2.3.5. Effect on Total Soluble Solids:

Total soluble solids (TSS) progressively increased during storage of the banana fruits. The maximum TSS value reached by the untreated fruits was 22.8% 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

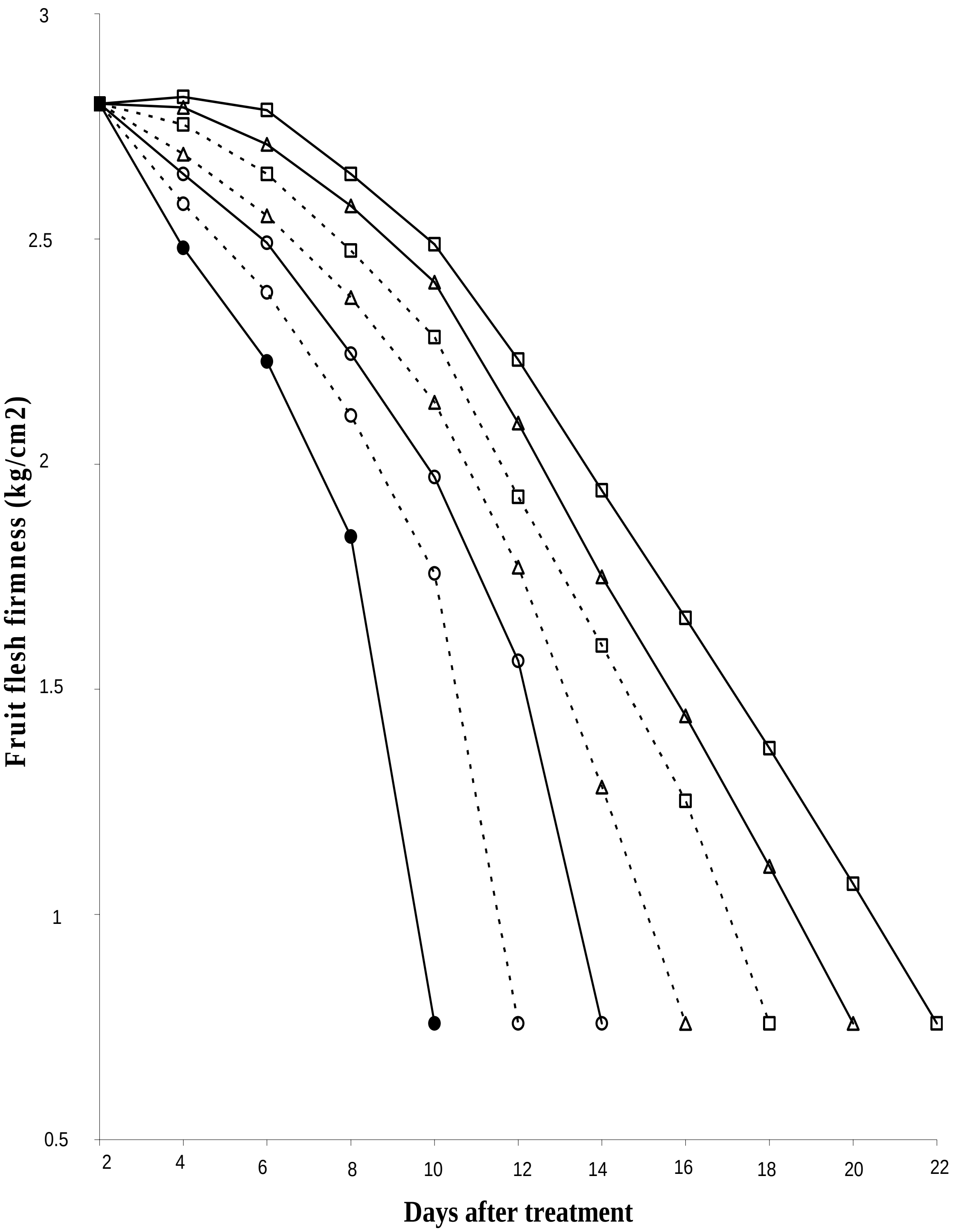

Fig.4: Fruit flesh firmness changes of banana fruits in carton boxes lined with perforated (----) or sealed (—) polyethylene films without $KMnO_4$ (o) or with $KMnO_4$ absorbed in filter paper (Δ) or $KMnO_4$ granules (□), compared to control fruits in carton boxes unlined and without $KMnO_4$ (●), during storage at 18± 2°C and 90-95% RH.

atmosphere conditions which delay fruit ripening (Dadzie and Orchard, 1997; Elkashif *et al.,* 2005; Kader, 1992). John and Marchal (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.

$KMnO_4$ in both forms, absorbed in filter paper or granules, in combination with perforated polyethylene lining reached the maximum TSS value six and eight days later, respectively, compared to the untreated fruits. $KMnO_4$ in filter paper or granules with sealed polyethylene films reached the maximum TSS value eight and ten days later compared to the control, respectively. This was in agreement with previous reports that ethylene absorbents in combination with polyethylene film lining slows down the onset of ripening and sugar accumulation in mangoes (Illeperuma and Jayasuriya, 2002).

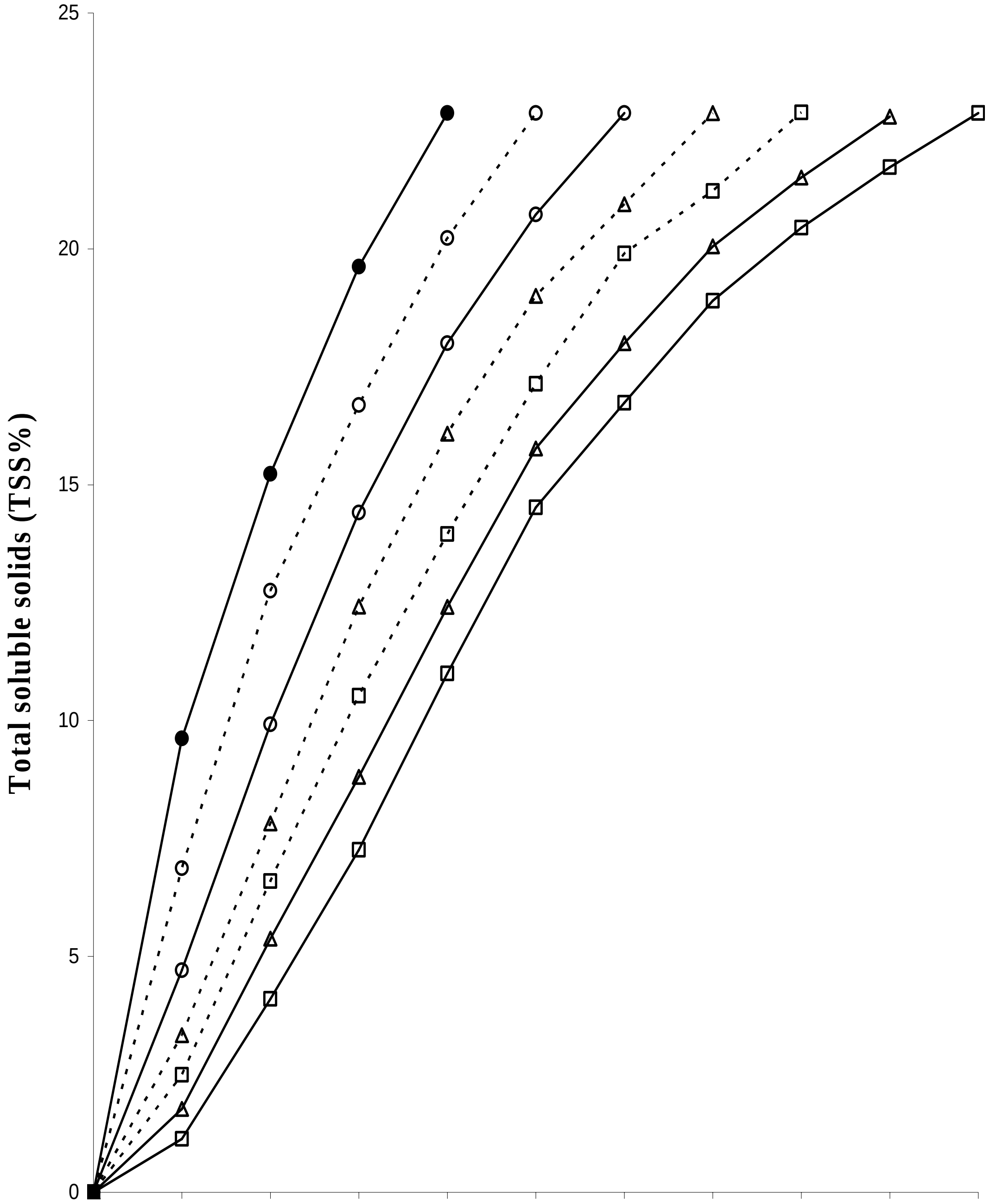

Fig.5: Total soluble solids of banana fruits in carton boxes lined with perforated (----) or sealed (—) polyethylene films without KMnO4 (o) or with KMnO4 absorbed in filter paper (Δ) or KMnO4 granules (□), compared to control fruits in carton boxes unlined and without KMnO4 (•), during storage at 18± 2°C and 90-95% RH.

Conclusion

Polyethylene film lining, either sealed or perforated, delayed the ripening of banana fruits. Potassium permanganate in both forms (granules and absorbed in filter paper) in addition, resulted in more delaying in fruit ripening. The effect in fruit ripening was indicated by retarded respiratory climacteric, delayed color development, increase total soluble solids, decreased fruit softening and weight loss percentage.

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