Effect of ethylene released from Ethrel in alkaline medium on banana (*Musa* spp.) fruit ripening

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ABSTRACT

The effect of ethylene gas, released from Ethrel in alkaline medium, on banana fruit ripening was evaluated. 'Dwarf Cavendish' banana fruits were obtained from a private orchard in Sinja, 400 kilometers south of Khartoum. The fruits were harvested at the 'full three quarters' maturity stage and transported to the laboratory at the Department of Horticulture, Faculty of Agriculture, University of Khartoum. They were washed with water to remove latex and dust, treated with 10% sodium hypochlorite as a disinfectant and air-dried. The fruits were treated with ethylene gas released from Ethrel at 0 (control), 250, 500 and 1000 ppm for 24 hrs. in hermetically sealed 20 l plastic chambers. Calculated amount of Ethrel that release the desired ethylene gas concentration was added to a beaker containing 15 ml of 40% Na OH in each chamber and immediately closed. After 24 hrs., the chambers were opened and fruits were placed in carton boxes lined with perforated polyethylene films and kept at 18±1˚C and 80%-85% relative humidity. Treatments with ethylene gas released from Ethrel at 250, 500, and 1000 ppm significantly accelerated fruit ripening, the higher the concentration the more was the effect. Depending on concentration, ripening was 2-5 days earlier in the treated fruits, compared with the control. The untreated fruits reached the climacteric peak of respiration after 10 days. Ethylene treatment at 250, 500, and 1000 ppm significantly accelerated the onset of the climacteric peak by 2, 4 and 5 days, respectively, compared with the untreated fruits. The effect of ethylene released from Ethrel on banana fruit ripening was also indicated by increased peel color development, total soluble solids (TSS), total and reducing sugars accumulation and enhanced fruit softening and weight loss.

INTRODUCTION

Banana (*Musa* spp.) is the most popular fruit crop in the Sudan for its nutritive value, low price and availability all year round. It is grown in almost every State, with annual production of 910 thousand metric tons (HSA, 2017).

Bananas are harvested green at about the 75% mature stage and are ripened in the market areas. Fruits that are allowed to ripen on the tree often split and tend to be mealy (Kader, 2002). Ripening is initiated by either natural evolution of endogenous ethylene as the fruit reaches full maturity or commercially by using exogenous ethylene (Marriott, 1980).

The use of ethylene gas in achieving faster and more uniform ripening of fruits is well documented (Kader, 2002). Many scientists duplicate the effects of ethylene gas by the use of aqueous solution of Ethrel (2-chloroethyl phosphonic acid). Ripening is promoted in many harvested fruits by dipping in Ethrel aqueous solutions (Ibrahim *et al*., 1994; Mohamed and Abu-Goukh, 2003; Mohamed-Nour and Abu-Goukh, 2010). Ethrel has the disadvantage of having to be applied to fruits in aqueous solution, an extra step in handling, which increases cost and enhances spread of diseases (Pantastico *et al*., 1975). In the presence of alkaline medium, ethylene evolves from Ethrel (Thompson and Seymour, 1982). A calculated amount of Ethrel (200 ml) of active ingredient if added to enough sodium hydroxide, will allow the release of about 28 thousand cubic centimeters of ethylene gas (Kader, 2002). Commodities treated with ethylene gas liberated from Ethrel in alkaline medium promoted fruit ripening in mango (Mohamed and Abu-Goukh, 2003) and guava (Mohamed-Nour and Abu-Goukh, 2010). Ethylene gas released from ethrel was more effective in triggering fruit ripening than dipping fruits in aqueous solution of Ethrel in mango (Mohamed and Abu-Goukh, 2003) and guava (Mohamed-Nour and Abu-Goukh, 2010).

This study was conducted to evaluate the effect of ethylene gas liberated from Ethrel in alkaline medium on banana fruit ripening.

MATERIALS AND METHODS

Experimental material

'Dwarf Cavendish' banana fruits were obtained from a private orchard in Sinja area, 400 km south of Khartoum. Fruits were harvested at the ‘full three quarters’ mature-green stage. The bunches were transported to the laboratory, dehanded and divided into fingers. The fruits were selected for uniformity of size, color and freedom from blemishes and defects. The fruits were washed with tap water to remove latex and dust, treated with 10% sodium hypochlorite (Clorox, 52g Cl/l) as a disinfectant and air-dried.

Fruit treatment

The banana fruits were distributed among the four treatments in a completely randomized design with four replicates. The treatment with ethylene released from Ethrel was carried out in 20-l plastic chambers. The fruits and a beaker containing 15 ml of 40% Na OH were put in each champer. Calculated amounts of Ethrel that would release ethylene gas of 250, 500 and 1000 ppm, calculated according to the free space volume, were added quickly to the beaker of Na OH and the chambers was immediately closed. The untreated (control) fruits were kept and closed in similar 20-l plastic chambers. All chambers were opened 24 hours later. Fruits were placed in carton boxes (50× 30× 20 cm) lined with perforated polyethylene films and stored at 18±1˚Cand 80%-85% relative humidity.

Parameters studied

Respiration rate was determined daily during the ripening period on 15 fruits from each replicate in a flowing system by the total absorption method of Charlimers (1956), as modified by (Mohamed-Nour and Abu-Goukh, 2010) and expressed in mg CO_2/ kg-hr.

Peel color was determined daily during the ripening period on the same fruits used for respiration and weight loss determinations. The banana color chart developed by Chiquita of United Brands Company was used in estimating color score. Color index no. 1,

completely green; no. 2, green with some trace of yellow color; no. 3, more green than yellow; no. 4, more yellow than green; no. 5, yellow with green tips; no. 6, fully yellow and no. 7, yellow flecked with brown (Chiquita Brands Inc., 1975).

Weight loss percentage was determined every day on the same 15 fruits used for determination of respiration rate. A digital sensitive balance was used to determine fruits weight and weight loss 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 weight of the fruits and W_t is the weight of the fruits at the designated time.

Fruit flesh firmness, total soluble solids (TSS), total and reducing sugars and ascorbic acid contents were determined every two days, and later every day, in two fruits picked randomly from each replicate, other than those used for respiration, peel color and weight loss determinations. Fruit flesh firmness was determined by Magness and Taylor firmness tester (D. Ballauf Meg. Co.), equipped with an 8 mm-diameters plunger tip. Two readings were taken from opposite sides of each fruit after the peel was removed, and was expressed in kg/cm^2. Total soluble solids (TSS) were measured directly from the fruit juice extracted by pressing the fruit pulp in a garlic press, using Kruss hand refractometer (model HRN-32). Two readings were taken from opposite sides of each fruit and the mean values were calculated and corrected according to the refractometer chart.

Total and reducing sugars were determined in the pulp extracts. Thirty grams of fruit pulp from each replicate were minced and homogenized in 100 ml of distilled water for one minute in a Sanyo solid state blender (model 241 HZ) and centrifuged at 10,000 rpm for 10 min in a Gallenkamp portable centrifuge (CF 400). The volume of the supernatant, which constitute the pulp extract, was determined. Total sugars were determined according to the anthrone method of Yemm and Willis (1954). Reducing sugars were measured according to the technique described by Somogyi (1952). Total and reducing sugars were expressed in g/100 g fresh weight.

Thirty grams of pulp from the fruit were homogenized in 100 ml of oxalic acid for one minute in an electric mixer (Molinex model No. 241) and centrifuged at 10,000 rpm for 10 minutes in a Gallenkamp potable centrifuge (CF-400). The volume of the supernatant was topped to 250 ml oxalic acid. Ascorbic acid content was determined using 2,6-dichlorophenol-indophenol titration method of Ruck (1963) and was expressed in mg/100g fresh weight.

Statistical analysis

Analysis of variance, followed by Fisher's protected LSD test with a significance level of $P \leq 0.05$ was performed on the data (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Ethylene gas released from Ethrel triggered fruit ripening in banana at all concentrations used, the higher the concentration, the higher the ripening rate. The effect on ripening was reflected in changes in respiration rate, peel color, weight loss, flesh firmness, total soluble solids (TSS), total and reducing sugars and ascorbic acid content.

Effect on respiration rate

The respiration curves, in all treatments, exhibited a typical climacteric pattern with a climacteric peak at 35.1 mg CO_2/ kg-hr. in untreated fruits. (Fig.1). Respiration rate was slightly higher in the ethylene treated fruits. This agrees with previous reports in mango (Mohamed and Abu-Goukh, 2003) and guava (Mohamed-Nour and Abu-Goukh, 2010). The untreated fruits had reached the climacteric peak after 10 days at 18±1˚C and 80 -85% relative humidity. Fruits treated with ethylene released from Ethrel at 250, 500, and 1000 ppm had reached the climacteric peak 2, 4 and 5 days earlier than the untreated fruits, respectively (Fig.1). This is in agreement with earlier reports (Mohamed-Nour and Abu-Goukh, 2010). Ethylene gas was reported to be many folds more effective in triggering the climacteric peak than Ethrel in aqueous solution (Ibrahim *et al*., 1994) and ethylene gas released from Ethrel was more effective than dipping fruits in the aqueous solution of Ethrel in mango (Mohamed and Abu-Goukh, 2003) and guava (Mohamed-Nour and Abu-Goukh, 2010).

Effect on peel color

Peel color score progressively increased during ripening of banana fruits regardless of the treatment. The untreated fruits reached the full yellow stage (color score 7) after 14

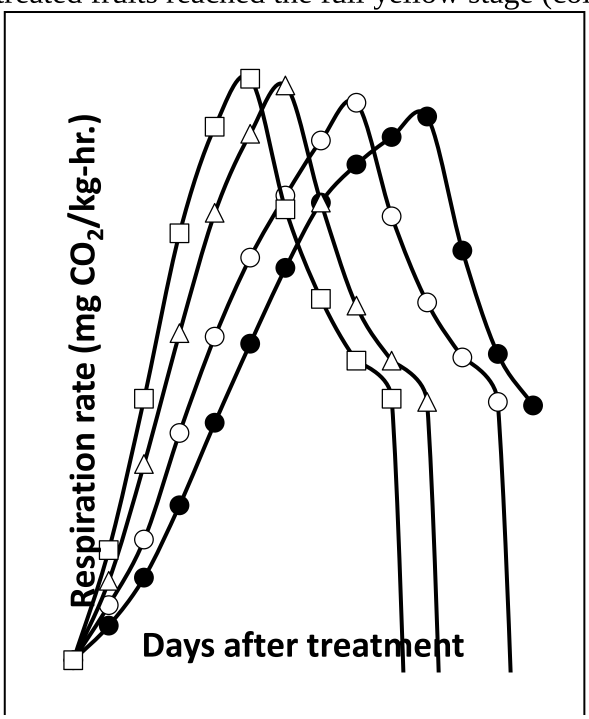

Fig. 1. Changes in respiration rate during ripening of 'Dwarf Cavendish' banana fruits treated with ethylene released from Ethrel at 250 (○), 500 (Δ) and 1000 ppm (□), compared with untreated fruits (●) at 18± 1 °C and 80% - 85% relative humidity.

days (Fig. 2). The fruits treated with ethylene liberated from Ethrel at 250, 500 and 1000 ppm reached the full yellow stage 2, 4 and 5 days earlier than untreated fruits, respectively (Fig. 2). Color development induced by applied ethylene and ethylene releasing compounds has been demonstrated to be through reduction in chlorophyll concentration and increase in carotenoid pigments. Ethrel was also reported to hasten color development and chlorophyll degradation in many fruits, including banana (Ibrahim *et al*., 1994), mango (Mohamed and Abu-Goukh, 2003) and guava (Mohamed-Nour and Abu-Goukh, 2010). The link between ethylene action and cartenoid level was well recognized (Lakshminarayana *et al*., 1975). Yamauchi *et al*. (1997) related the acceleration of chlorophyll degradation by ethylene treatment, to the enhancement of chlorophyllide which is formed by the action of chlorophyllase. El Rayes (2000) reported that Ethrel treatment increased markedly peel color, skin cartenoids, TSS, vitamin C and juice content.

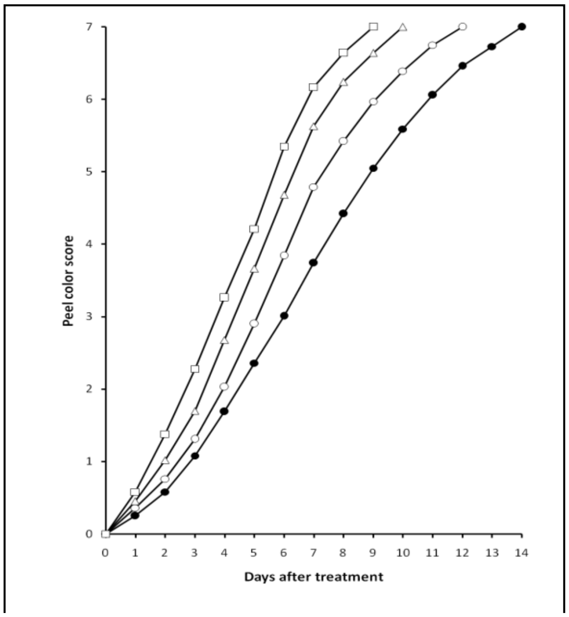

Fig. 2. Changes in peel color during ripening of 'Dwarf Cavendish' banana fruits treated with ethylene released from Ethrel at 250 (○), 500 (Δ) and 1000 ppm (□), compared with untreated fruits (●) at 18± 1 °C and 80% - 85% relative humidity.

The higher the concentration of Ethrel applied, the lower the chlorophyll content in fruit peel, the higher the carotenoids, TSS, vitamin C and juice content. It was reported that ethylene released from Ethrel in alkaline medium was more effective in peel color development than dipping fruits in aqueous solution of Ethrel in mango (Mohamed and Abu-Goukh, 2003) and guava (Mohamed-Nour and Abu-Goukh, 2010).

Effect on weight loss

Weight loss progressively increased during ripening of banana fruits regardless of treatment (Fig. 3). Weight loss was followed until the fruits reached the full yellow stage (color score 7). At that stage, the control fruits reached the highest weight loss percentage of 19.9% after 14 days. The fruits treated with ethylene released from Ethrel accelerated the increase in weight loss percentage during ripening of banana fruits, and reached the same weight loss percentage (19.9%) 2, 4 and 5 days earlier in fruits treated with 250, 500 and 1000 ppm ethylene gas released from Ethrel, respectively, compared with the control (Fig. 3).

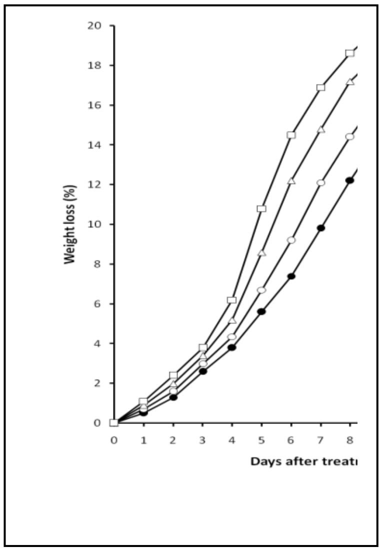

Fig. 3. Changes in weight loss during ripening of 'Dwarf Cavendish' banana fruits treated with ethylene released from Ethrel at 250 (○), 500 (Δ) and 1000 ppm (□), compared with untreated fruits (●) at 18± 1 °C and 80% - 85% relative humidity.

Effect on fruit flesh firmness

Fruit flesh firmness of banana fruits had showed a progressive decline during ripening. The decline in flesh firmness observed in the untreated fruits was about 11-folds from the hard mature-green stage (2.11 kg/cm² shear resistance) to the final soft ripe stage (0.2 kg/cm²). This was reached in 14 days in the banana fruits (Fig. 4). Similar drop in fruit flesh firmness was reported in mango (Abu-Goukh and Abu-Sarra, 1993; Mohamed and Abu-Goukh, 2003) and guava fruits (Abu-Goukh and Bashir, 2003; Mohamed-Nour and Abu-Goukh, 2010). Banana fruits treated with ethylene released from Ethrel at 250, 500 and 1000 ppm had reached that final soft stage (0.2 kg/cm^2) 2, 4 and 5 days earlier, respectively, compared with the untreated fruits (Fig. 4). It was reported that post-harvest treatment with ethylene released from Ethrel promoted fruit ripening in mango (Mohamed and Abu-Goukh, 2003) and guava (Mohamed-Nour and Abu-Goukh, 2010) and the treated fruits were less firm than the control at any time during the course of ripening.

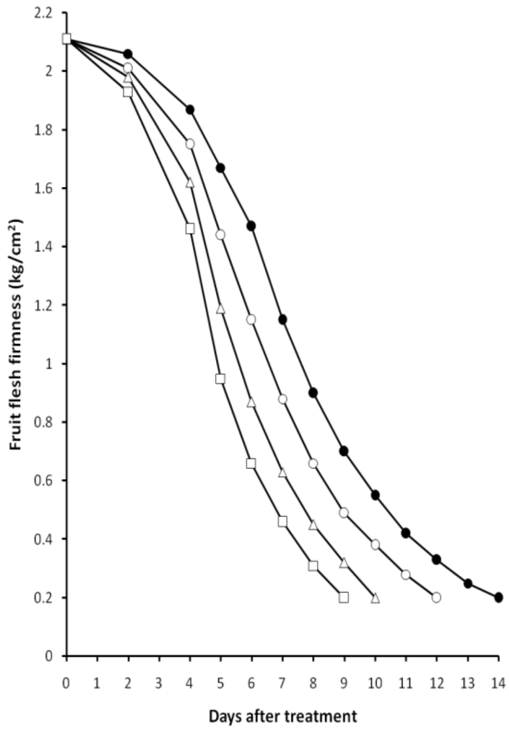

Fig. 4. Changes in flesh firmness during ripening of 'Dwarf Cavendish' banana fruits treated with ethylene released from Ethrel at 250 (○), 500 (Δ) and 1000 ppm (□), compared with untreated fruits (●) at 18± 1 °C and 80% - 85% relative humidity

… fruits. The maximum … g. 5). The treated fruits reached that maximum value 2, 4 and 5 days earlier at 250, 500 and 1000 ppm, respectively, compared with the control. Post-harvest treatment with ethylene or Ethrel induced fruit ripening and increased TSS in bananas (Ibrahim *et al*., 1994), mangoes (Mohamed and Abu-Goukh, 2003), oranges (El Rayes, 2000) and guavas (Mohamed-Nour and Abu-Goukh, 2010)

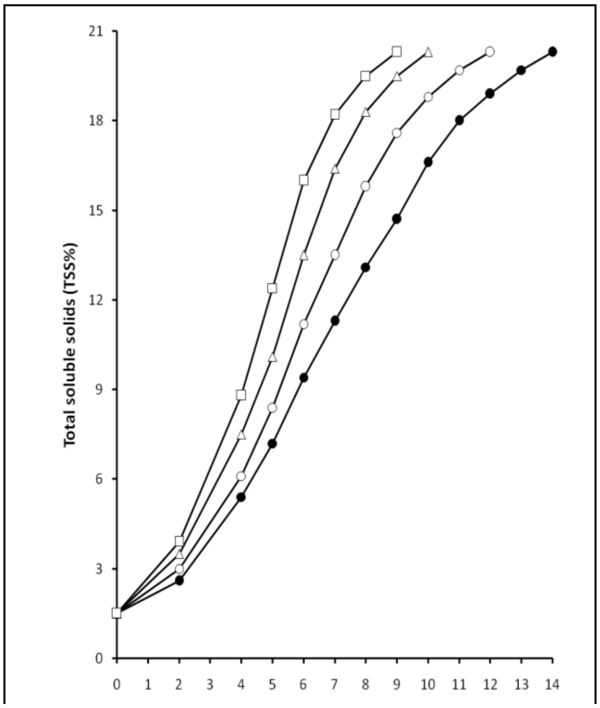

Fig. 5. Changes in total soluble solid during ripening of 'Dwarf Cavendish' banana fruits treated with ethylene released from Ethrel at 250 (○), 500 (Δ) and 1000 ppm (□), compared with untreated fruits (●) at 18± 1 °C and 80% - 85% relative humidity.

Effect on total sugars

Total sugars steadily increased in banana fruits during ripening (Fig. 6). A similar trend in total sugars during ripening was reported in banana (Ibrahim *et al*., 1994), mango (Abu-Goukh and Abu-Sarra, 1993) and papaya (Abu-Goukh *et al*., 2010). The remarkable increase in total sugars observed after the climacteric peak was attributed to the increase in activity of enzymes responsible for starch hydrolysis and for decline in the rate of sugars breakdown by respiration (Bashir and Abu-Goukh, 2003). The maximum total sugars value reached by the untreated fruits was 18.1 g/100g fresh weight after 14 days. The treated fruits reached the maximum total sugars in 2, 4 and 5 days earlier, respectively, compared with the control. Ethylene and ethylene releasing compounds were demonstrated to induce fruit ripening and to increase total sugars in banana (Ibrahim *et al*., 1994), mango (Mohamed and Abu-Goukh, 2003) and guava (Mohamed-Nour and Abu-Goukh, 2010). Total sugars were about 89% of TSS at the different stages of ripening. This is in agreement with earlier reports (Abu-Goukh and Abu-Sarra, 1993; Abu-Goukh *et al*., 2005).

Effect on reducing sugars

Reducing sugars in the banana pulp increased from 0.8 g/100g fr. wt. in the mature-green fruits, reaching a peak of 12.9 g/100g, which coincided with the peak of respiration in all fruits, and subsequently decreased thereafter (Fig. 6). A similar pattern of reducing sugars changes was reported in banana (Leopold and Kriedemann, 1975), mango (Abu-Goukh and Abu-Sarra, 1993; Abu-Goukh *et al*., 2005) and guava (Bashir and Abu-Goukh, 2003). The untreated fruits reached the peak of reducing sugars of 12.9 g/100g fr. wt. after 10 days, while the treated fruits with ethylene released from Ethrel at 250, 500 and 1000 ppm had reached that peak of reducing sugars 2, 4 and 5 days earlier, respectively, compared with the control (Fig. 6). Ethylene released from Ethrel at 250, 500 and 1000 ppm had induced ripening and enhanced the climacteric peak by 2, 4 and 5 days, respectively (Fig.1) and similarly enhanced the peak of the reducing sugars. During ripening, starch and sucrose are converted to glucose (Wills and Golding, 2016), which is the main substrate utilized in respiration (Phan *et al*., 1975).

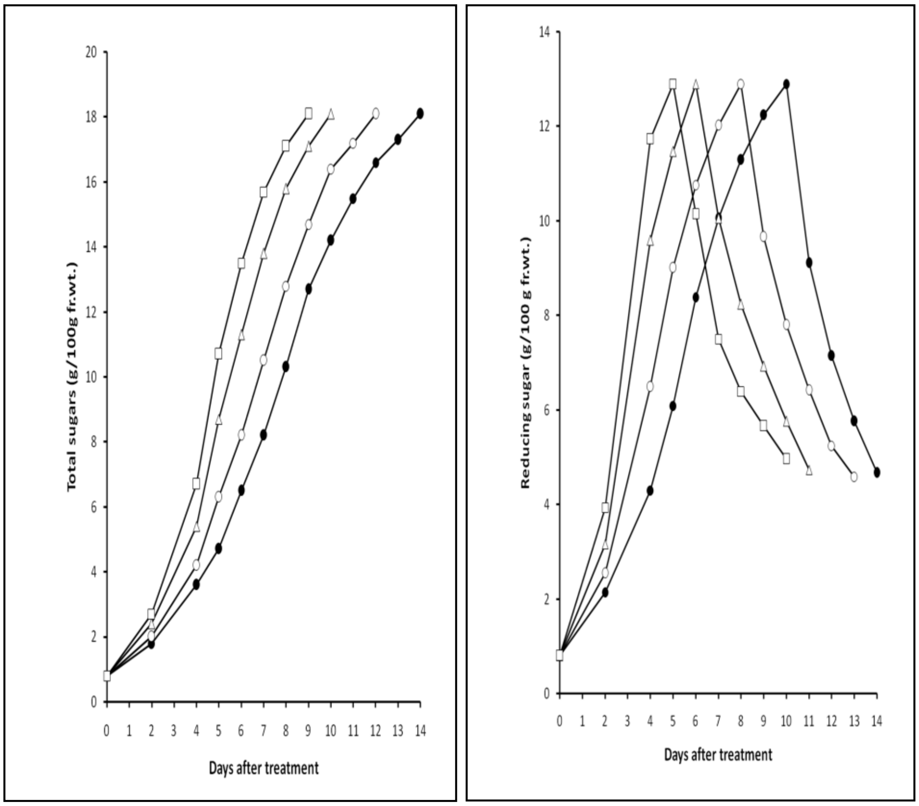

Fig. 6. Changes in total and reducing sugars during ripening of 'Dwarf Cavendish' banana fruits treated with ethylene released from Ethrel at 250 (○), 500 (Δ) and 1000 ppm (□), compared with untreated fruits (●) at 18± 1 °C and 80% - 85% relative humidity.

Effect on ascorbic acid content

Ascorbic acid content showed continuous decline during ripening of banana fruits in all treatments. It decreased from 13.0 mg/100g fresh weight in the mature-green fruits to 8.6 mg/100g in the ripe fruits (color score 7) (Fig. 7). This agrees with previous reports that ascorbic acid declines rapidly during ripening of mango (Abu-Goukh and Abu-Sarra, 1993), orange, pineapple (Adisa, 1986), and guava (Basher and Abu-Goukh, 2003). The untreated fruits reached the lowest ascorbic acid content of 8.6 mg/100g after 14 days. The fruits treated with ethylene released from Ethrel at 250, 500 and 1000 ppm reached that lowest value 2, 4 and 5 days earlier, respectively, compared with the control (Fig. 7).

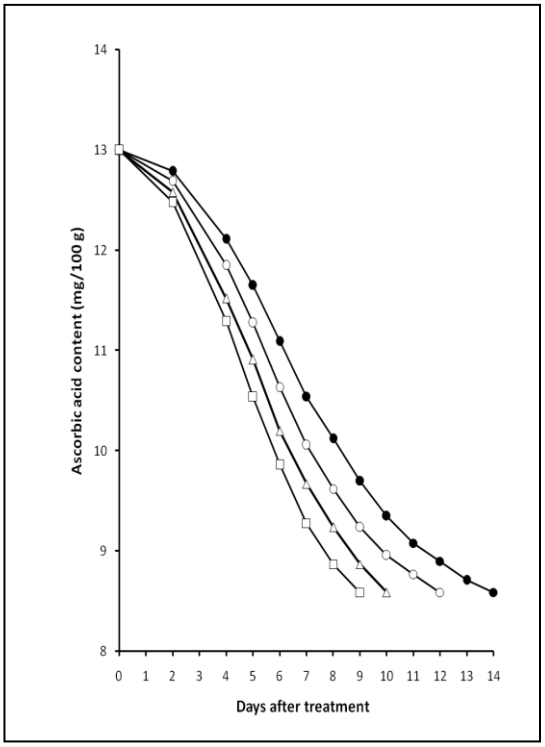

Fig. 7. Changes in ascorbic acid content during ripening of 'Dwarf Cavendish' banana fruits treated with ethylene released from Ethrel at 250 (○), 500 (Δ) and 1000 ppm (□), compared with untreated fruits (●) at 18± 1 °C and 80% - 85% relative humidity.

CONCLUSION

Treatment with ethylene released from Ethrel at 250, 500 and 1000 ppm significantly accelerated banana fruit ripening. Depending on concentration, ripening was 2-5 days earlier in the treated fruits, compared with the control. The effect of the ethylene released from Ethrel was also indicated by increased peel color development, TSS, total and reducing sugars accumulation and enhanced fruit softening and weight loss.

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تأثير الإثيلين المنبعث من الإثريل فى وسط قلوى على إنضاج ثمار الموز

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الخلاصة

قُوم تأثير غاز الإثلين المنبعث من الإثريل فى وسط قلوى على إنضاج ثمار الموز. وفرت ثمار الموز من صنف 'دوارف كافندش' من مزرعة خاصة فى منطقة سنجة، 400 كيلومتراً جنوب الخرطوم. حصدت الثمار فى مرحلة 'ثلاثة أرباع ممتلئة' من إكتمال النمو وتم ترحيلها إلى المعمل فى قسم البساتين، بكلية الزراعة، جامعة الخرطوم. غسلت الثمار بالماء لإزالة العصارة والأتربة وعوملت بهيبوكلوريت الصوديوم (10%) كمطهر ثم جففت الثمار بازالة الماء العالق بها بواسطة تيار من الهواء. عوملت الثمار بغاز الإثيلين المنبعث من الإثريل بتركيز صفر (شاهد) و 250 و500 و1000 جزء فى المليون لمدة 24 ساعة فى حاويات بلاستيكية محكمة الإغلاق سعة 20 لتراً. أضيفت الكميات المحسوبة من الإثريل التى تفرز التركيزات المطلوبة الى 15 ملى ليتر من هيدروكسيد الصوديوم (40%) وضعت فى كؤوس زجاجية داخل الحاويات واغلقت الحاويات مباشرة بعد ذلك. بعد 24 ساعة من المعاملة فتحت الحاويات ووضعت الثمار فى صناديق من الكرتون مبطنة بشرائح البولى إثيلين المثقب وحفظت على درجة حرارة 18±1 °م ورطوبة نسبية 80% - 85%. أدت المعاملة بالإثيلين المنبعث من الإثريل معنوياً إلى الإسراع بنضج ثمار الموز، وكان التركيز الأعلى أكثر فعالية. كان الإنضاج أسرع فى الثمار المعاملة بمقدار 5-2 أيام حسب التركيز، مقارنة بالثمار غير المعاملة. أدت المعاملة بغاز الإثيلين المنبعث من الإثريل معنوياً لتسريع وصول الثمار إلى ذروة التنفس. فقد وصلت الثمار غير المعاملة إلى ذروة التنفس، بعد 10 أيام، وقد تسارع معنوياً وصول الثمار المعاملة بغاز الإثيلين المنبعث من الإثريل بتركيز 250 و500 و1000 جزء فى المليون إلى ذروة التنفس 2 و4 و5 أيام، على التوالى، مقارنة بالثمار غير المعاملة. كما انعكس تأثير المعاملة بغاز الإثيلين، المنبعث من الإثريل، فى إنضاج ثمار الموز فى الزيادة فى تلوين القشرة الخارجية للثمار وتراكم المواد الصلبة الكلية الذائبة والسكريات الكلية والمختزلة والإسراع بليونة لب الثمار وفقدان الوزن فيها.