# Delaying tomato fruit ripening using ethanol vapor through a dynamic air-flow system

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# DELAYING TOMATO FRUIT RIPENING USING ETHANOL VAPOR THROUGH A DYNAMIC AIR-FLOW SYSTEM

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***Abstract***

Harvested mature-green tomato fruits were kept for 2 weeks at 14±2°C in a closed ambient connected to an air-flow system. The air-flow was enriched with ethanol vapor by passing through solutions of 0, 5, 10 or 15% ethanol before enriching the fruit ambient. By the end of the 2 weeks, fruits of 10 and 15% ethanol showed an approximate ripening block while those of 5 and 0% ethanol were at turning and red-ripe stages, respectively. During the period of exposure, ethanol vapor didn't develop fruit anaeroboisis and ceased pathogen growth with a minor level of fruit weight loss. Transferring such fruits to ethanol-free air at 14±2°C, allowed ripening to proceed and to develop but with a slower rate for the fruits of higher ethanol levels. Fruits of 5 and 10% ethanol successfully reached red-ripe stage 8 and 16 days after the termination of ethanol vapor exposure, respectively, without sensible impact on fruit quality. Fruits of 15% ethanol however, showed further ripening delay and hardly exceeded light-red stage with lower quality grads. Immediate ethrel dipping, after ethanol vapor exposure, only accelerated fruit ripening by about 3-4 days. While there were no significant differences among all treatments in terms of L-ascorbic acid content, a significant reduction was occurred in total soluble solids and titratable acidity for tomato fruits of 10% ethanol with further reduction for those of 15% ethanol. Nevertheless, only fruits of 15% ethanol showed a significant reduction in fruit panel taste. These data strongly indicated that without refrigeration, a dynamic air-flow system with low levels of ethanol vapor application can be used in delaying the subsequent tomato fruit ripening without sensible impact on the quality.

**KEYWORDS:**
TOMATO; ETHANOL VAPOR TREATMENT; ETHREL TREATMENT; RIPENING.

## 1. INTRODUCTION

For successful exportation or marketing at long distances, tomato fruits are usually harvested at mature-green or at breaker stage. Such fruits are known by their chilling sensitivity and must be held at temperatures above 13 °C (threshold

temperature for mature-green fruits) to eliminate the subsequent appearance of chilling injury symptoms at marketing (Morris, 1982). Ripening delay of harvested mature-green tomato fruits without refrigeration, therefore, is a practical management required to be achieved for successful exportation and long distances marketing.

Using non-volatile chemicals for such purpose became commercially un-advisable due to the higher residue levels of such chemicals at the stage of consumption which may adversely affect not only fruit quality but also human health and environmental safety.

Ethanol is a volatile compound naturally produced by plant tissues under anaerobic conditions (Kelly and Saltveit, 1988; Saltveit and Ballinger,1983). It is also accumulated in a short period of anaerobically stored fruits without adversely affecting fruit subsequent quality (Saltveit and Balliger,1983; Ke *et al.*, 1990). Furthermore, some fruits are normally ethanol producers under aerobic conditions (Smock, 1944). Exogenous application of ethanol vapor reversibly inhibited tomato fruit ripening via inhibiting ethylene biosynthesis and action (Saltveit and Mencarelli, 1988) without reducing fruit quality as they subsequently reached red-ripe stage (Saltveit and Sharaf 1992). Levels of ethanol residues were diminished in such fruit 72h after transferring to ethanol-free air (Saltveit and Sharaf 1992). Among other alcohols, ethanol is more effective in inhibiting tomato fruit ripening and has the least phytotoxic effect (Wu *et al.*, 1992). It was also used in solution to delay carnation senescence via inhibiting the climacteric ethylene (Heins, 1980).

In an opposite trend to ethanol inhibitory impact on tomato fruit ripening, ethrel (2-chloroethan-phosphonic acid) is commercially used for enhancing tomato fruit ripening (Abeles, 1992).

Attempts for inhibiting tomato fruit ripening using ethanol vapor were carried out in a closed chamber as a static system designed for a short period of exposure. In this work however, ethanol vapor was used through a dynamic air-flow system for a long period of exposure, as a sort of controlled atmosphere, to delay or block tomato fruit ripening (during exportation) followed by ethanol-free air exposure or ethrel application at final destination to allow or speed fruit ripening, respectively.

## 2. MATERIALS AND METHODS

### *Plant material*

Tomato (*Lycopersicon esculentum* Mill.) seeds cv. Castle Rock were sown in foam trays filled with a mixture of peatmoss: vermiculite (1:1 volume) on March 1st. of both 1994 and 1995 seasons. Trays were then kept under unheated greenhouse conditions and all recommended nursery managements were used for producing one month old healthy seedlings. Seedlings were then transplanted into the open field in Shalakan farm, Faculty of Agriculture, Ain Shams University, 30 cm apart in 5m long rows of 80cm width. This was carried out in 3 replicates each was

comprised of 8 rows. All agricultural managements were carried out as usually recommended for tomato crop production in the open field. At mature-green stage, fruits were harvested early morning and directly transferred to the Horticultural Department of the above mentioned institute. In each replicate fruits were sorted, size graded (with an approximate diameter of 7cm), washed with chlorinated water (500ppm NaOCl), then air dried , weighed and exposed to the deformation tester for recording fruit initial fresh weight and softness, respectively. Fruits were then distributed among the below described treatments:

***Ethanol vapor application***

Treating tomato fruits with ethanol vapor was carried out through an air-flow system (Atta-Aly and Brecht, 1995). This air-flow system was constructed and built as shown in Plate (2). Before fruit incubation, the whole air-flow set as well as fruit ambients were kept inside controlled storage room of 14$\pm$2°C and RH of 82$\pm$3%. Twenty mature-green tomato fruits were placed inside 5 liter glass jar (fruit ambient) and each 2 fruit ambients were considered as one replicate. The air-flow was passed through 500ml of ethanol solutions of 0,5,10 and 15 % ethanol before passing and enriching the fruit ambient with ethanol vapor. Each concentration of the used ethanol vapor was compressed of 3 replicates. The distilled water was used in diluting ethanol to the above mentioned concentrations to ensure saturated relative humidity in the air-flow. The out-come of the air-flow was connected to a rubber tube carrying it out of the storage room. The prepared solutions of different ethanol concentrations were changed and renewed every two days throughout the whole exposing period to ensure ethanol steady concentration. The excluded ethanol solutions were exposed to rotary evaporator which indicated the presence of ethanol with the almost appropriate concentration in each ethanol solution after the two days of use. After 14 days of continuos ethanol vapor exposure, fruits were transferred to the storage room of ethanol-free air after being dipped in $H_2O$ or 1000ppm ethrel as described below.

***Ethrel treatment***

After the termination of ethanol vapor treatments, fruits of each replicated were equally divided into two groups each was comprised of 20 fruits for the subsequent 10sec dipping in either $H_2O$ or 1000ppm ethrel. Using drops of concentrated hydrochloric acid, hydrogen ion concentration (pH) was adjusted to 5.5 in the distilled water used for direct fruit dipping or for ethrel preparation. Ethrel dipping was carried out for 10 sec to test ethylene releaser ability to overcome ethanol vapor inhibitory impact on tomato fruit ripening. Ethrel application was also carried out on mature-green fruits directly after harvesting to test fruit ripening response of such cultivar to ethrel application and to serve as an indicator to those previously exposed to ethanol vapor. Fruits were then air dried, backed in 40 X 30 X 10cm carton boxes with a capacity of 20 fruits per box, and directly kept in a store of ethanol-free air of the above mentioned conditions for monitoring fruit physical and chemical quality.

**Fruit analysis**

***Fruit physical analysis***

Fruit physical analysis were carried out in three replicates each was compressed of 15 fruits.

***Fruit softness***

It was determined using the Egyptian deformation tester as a non-destructive method for measuring fruit softness (Atta-Aly and El-Awady, 1993). After exposing the fruit to 500g load for 15 sec, fruit deformation (softness) was recorded in mm as described by Atta-Aly and El-Awady (1993). This analysis was carried out on the same individual fruits before and after ethanol vapor exposure as well as, every 7 days during storage until fruits reached red-ripe stage.

***Colour development***

Fruit colour was visually monitored during the period of ethanol vapor application. During ethanol-free air storage however, fruit ripening score was determined using the colour chart of Color Classification Requirements In United States Standards For Grades Of Fresh Tomatoes (1975) at 4 days intervals.

***Percentage of fruit weight loss (% WL)***

Fruits initial weight were recorded before ethanol vapor exposure. By weighing same fruits at the end of ethanol vapor treatment as well as, every 7 days during storage, fruit % WL was calculated until fruit reached red-ripe stage.

***Percentage of decayed fruits (% Dec.)***

Fruits showed any sign of decay development either during ethanol vapor treatment or during storage were counted and the percentage of decayed fruits was calculated on the bases of total fruits number.

***Days to reach red-ripe stage***

In each treatment, days required for the fruits to reach red-ripe stage were recorded.

***Fruit panel taste***

At red-ripe stage 9 fruits (3 fruits/replicate) were sliced and exposed to the panel taste by 15 persons who gave a taste descending order starting with grade 5 as the highest taste quality according to the method of Mizrahi (1982).

Due to the variability between treatments in the time required for the fruits to reach red-ripe stage, fruits of each two close ethanol treatments, of the first season, arrived to red-ripe stage almost together were exposed to the panel taste. At the final stage however, all panel tastes were referred to control fruits. During the second season however, the differences between treatments in the time required for the fruits to reach red-ripe stage, which have been calculated during the first season,

were used for introducing the fruits to the air-flow system in a timed table to obtain fruits at red-ripe stage from all treatments in one single day for more accurate panel taste analysis.

***Fruit chemical analysis***

With the exception of fruit respiration which carried out before the termination of ethanol vapor application, the remaining analysis were carried out at red-ripe stage in three replicates each was comprised of 5 fruits.

***Respiration rate***

Carbon dioxide produced by tomato fruits was determined one day before the end of ethanol exposing period to test if fruit respiration remained aerobic or anaerobic respiration was developed. The air-flow was passed through concentrated NaOH, before passing into the fruit ambient to insure that air-flow is $CO_2$ free. The out-coming air-flow from each ambient was then passed into 500ml of 0.1N NaOH for one hour. Such solution was then titrated against 0.1N of $H_2SO_4$ (A.O.A.C. 1970) and carbon dioxide produced by the fruits was calculated as mg $CO_2$/kg fruits.

***Titratable acidity (% TA)***

Two hundred grams of tomato fruit tissues were homogenized in a blender. The homogenized was then filtered using Watmann paper No.1 and the obtained juice was centrifuged at 3000rpm. The obtained clear juice was titrated against 0.1N of NaOH and the % TA was calculated on the basis of citric acid as described by A.O.A.C. (1970).

***Total soluble solids (TSS)***

A hand refractometer was used for measuring TSS level in the tomato juice using drops of the previously extracted clear juice. Data were then recorded as % TSS.

***L-ascorbic acid (LAA)***

One hundred grams of tomato fruit tissues were homogenized with 100ml of 6% oxalic acid in a blender. The extraction was filtered and centrifuged as previously described. Twenty ml of the extracted juice was placed in 100ml measuring flask and the volume was completed using 3% oxalic acid, and 10ml were then titrated against 2,6 dichlorophenolendophenol dye following the methods of Sale (1946). Data were then calculated and recorded as mgLAA/100g fruit fresh tissues.

***Experimental design and statistical analysis***

Experiments were designed as factorial complete randomized design in 3 replicates. With the exception of fruit panel taste, data means of the other parameters were paired as combined analysis since the results of both seasons followed the same pattern. Data were then analyzed for statistical significant

differences using Dancan's multiple range test. The standarized least significant range (LSR) at 5% level was used to compare the effect of various treatments according to Little and Hills(1978).

## 3. RESULTS

Dipping mature-green tomato fruits cv. Castle Rock in 1000ppm ethrel significantly accelerated fruit ripening as indicated by the shortest time required for such fruits to reach red-ripe stage in comparison with those of control (12 vrs 20 days, respectively) during the two respective seasons (Table 1). At red-ripe stage and with the exception of fruit firmness and weight loss which significantly reduced by ethrel dipping, there were no significant differences between control and ethrel treated fruits in terms of total soluble solids (TSS), titratable acidity (TA) and L-acorbic acid (LAA) contents (Table 1). These data strongly indicated that tomato fruit ripening of such cultivar have the positive response to ethrel application.

Exposing mature-green tomato fruits to an air-flow, supplemented with ethanol vapor by passing through solutions of different ethanol concentrations, for 14 days inhibited fruit respiration (Fig. 1). This inhibition slightly increased as ethanol concentration increased. Fruits of 5% ethanol were slightly lower than control while fruits of 10 and 15 % ethanol were significantly lower only than those of control ones (Fig. 1). In addition, no significant differences in fruit respiration were detected among different applied levels of ethanol but rather slight reduction with increasing ethanol level (Fig. 1)

During the period of ethanol vapor exposure, control fruits (exposed to ethanol-free air) were almost at light-red stage and some colour development was visually noticed on the fruits of 5 % ethanol, while those of higher ethanol levels remained almost green (day 0 at Table 2). After the period of ethanol vapor exposure and during storage at $14\pm2$°C, the subsequent ripening development, measured as fruit ripening score, strongly delayed (Table 2) while days required to reach red-ripe stage showed a significant increase (Fig.2). These findings were more pronounced as ethanol concentration increased (Table 2 and Fig. 2). Fruits of 5, 10 and 15 % ethanol, reached red-ripe stage 8 , 16 and 24 days after the termination of ethanol vapor treatment, respectively. Immediate dipping in 1000ppm ethrel after ethanol vapor treatment shortened the time required for the fruits to reach red-ripe stage by about 4-5 days for the fruits of 10 - 15 % ethanol and by about 2-3 days for the fruits of 5 % ethanol of both seasons (Table 2 and Fig, 2).

Fruit softness, weight loss and the percentage of decayed fruits were determined at weekly intervals during storage at $14\pm2$ °C excluding fruits passed red-ripe stage (Table 3). While fruits became significantly softer as the storage time extended, no significant differences were detected among the fruits of different ethanol levels at each sampling date (Table 3). The subsequent ethrel dipping after ethanol vapor application produced softer fruits than those dipped in water (Table 3).

In terms of fruit weight loss, no significant differences were detected among fruits of different ethanol levels by the end of ethanol vapor exposing period (Table 3). During the storage time however, fruits of higher ethanol levels showed lower weight loss at each sampling date. The subsequent ethrel dipping however, resulted higher levels of fruit weight loss (Table 3).

The highest decay level was noticed on control fruits during the period of ethanol vapor exposure (Table3). Such decay significantly reduced as ethanol concentration increased reaching 0% decay at the highest ethanol level (Table 3). During storage at $14\pm2^{o}C$ however, more decay was developed but with lower percentages for the fruits of higher ethanol concentration at each sampling date. Subsequent ethrel application had no clear impact on fruit decay during storage (Table3).

Fruit content of LAA at red-ripe stage, showed no significant differences among ethanol levels. This was evident with or without subsequent ethrel application of both seasons (Table 4). A gradual reduction in fruit content of %TA and %TSS however, was observed at the subsequent red-ripe stage with the previous increase in ethanol concentrations regardless ethrel application (Table 4).

Fruit panel taste during the first season, showed no significant differences between fruits of 5 % or those of 10 % ethanol compared to those of control at red-ripe stage regardless the subsequent ethrel application (Fig. 3). When ethanol level rose up to 15%, fruit panel taste strongly reduced with or without the subsequent ethrel application (Fig. 3). Fruit panel taste during the second season followed the same pattern of the first season (Fig. 4).

## 4. DISCUSSION

Tomato fruits are usually harvested at mature-green stage if picked for the purpose of exportation. Delaying tomato fruit ripening during exportation is deeply required while ripening acceleration is an essential process at final destination or for early local market supply. Delaying tomato fruit ripening by keeping at low temperatures, which is usually used for ripening delay (Lutz and Hardenburg, 1968), can not be used due to fruit sensitivity to chilling injury (Ryall and Lipton, 1979). Therefore, delaying tomato fruit ripening without refrigeration is the key for successful exportation. Finding alternative techniques other than refrigeration for delaying tomato fruit ripening is the main purpose of such study.

It is well known that during exportation fruits of different species may be shipped together and the emanated ethylene by fruits of a certain specie may accelerate fruit ripening of the other species. Inhibiting ethylene biosynthesis, therefore, is not an effective method for delaying fruit ripening unless fruits of one specie are shipped alone without mixing. Inhibiting ethylene action is rather needed under such circumstances. Furthermore, the ultimate and perfect choice is a treatment with a safe substance which can inhibit both ethylene biosynthesis and action. It has been proved that ethanol inhibited ethylene biosynthesis and action (Saltveit and

Mencarelli, 1988; Saltveit and Sharaf, 1992). Furthermore, ethanol is also a natural product of some fruits even under aerobic conditions (Smok, 1944). It is also produced with anaerobic conditions and a fast relief was occurred when fruits were returned back to the aerobic conditions (Saltveit and Ballinger, 1983; Saltveit and Sharaf, 1992). A short period of anaeroboises is usually used for reducing fruit sensitivity to chilling injury (Pesis *et al.*, 1994). Long period of anaeroboises however, resulted unmarketable fruits and remarkably increased postharvest losses due to fruit fermentation (Woodward and Topping, 1972). It is of interest to note that aerobic fruit respiration declined with reducing $O_2$ or increasing $CO_2$ level in the fruit ambient. In contrast, a dramatic increase in fruit respiration was occurred under anaerobic conditions (Woodward and Topping, 1972). Data presented in Fig (1) showed that the levels of ethanol used in this work (i.e. 0, 5, 10 and 15 %) did not develop anaerobic respiration since no increase in fruit respiration was detected after 13 days of continuos ethanol vapor exposure than those of control. These results strongly indicated the absence of anaeroboises and fruit fermentation during ethanol vapor exposure. It has been reported that ethylene promoted fruit respiration (Lyons and Pratt, 1964). Inhibiting ethylene biosynthesis and/or action, therefore, may be the reason behind reduced respiration levels of ethanol treated fruits than those of control (Fig.1). The significant increase in control fruit respiration over those of 10% and 15% ethanol may also due to the ripening progress (Table 2), since ripening of tomato fruits is combined by respiration climacteric rise (Lyons and Pratt, 1964).

On the other hand, fruit response to ethrel application, as an ethylene releaser, is varied based on species variability (Abeles *et al.*, 1992). Therefore, mature-green tomato fruits of Castle Rock cultivar were exposed to 1000ppm ethrel application to test fruit ripening response of such cultivar to ethrel application. Data presented in Table(1) showed that fruit ripening of such cultivar is positively correlated to ethrel application as noticed by ripening enhancement and firmness loss without affecting fruit quality measured as LAA, TA and TSS content. In terms of human safety, ethrel has been nationally registered for pre and postharvest uses in several fruits including tomato fruits with 1000ppm as a recommended concentration for postharvest use (Abeles *et al.*, 1992). The shorter time required for ethrel treated fruits to reach red-ripe stage was the reason behind its lower values of weight loss due to the shorter storage period compared to those of control (11 vs 19 days, respectively).

Based on its negative impact on ethylene biosynthesis and action (Saltveit and Mencarelli, 1988), ethanol vapor was used in this work, therefore, to delay or block tomato fruit ripening without refrigeration by designing an air-flow system allowing the air-flow to pass through ethanol solution of 0, 5, 10 or 15 % ethanol before enriching the fruit ambient kept at $14\pm2$°C (Plate 1). After two weeks of continuous ethanol vapor application, fruits where then transferred to ethanol-free air store of $14\pm2$°C after being dipped for 10 sec in either $H_2O$ or 1000ppm ethrel for ripening enhancement. It was noticed that ripening delay, measured as fruit ripening score (Table 2) or days to reach red-ripe stage (Fig. 2), was more pronounced in the fruits

of higher ethanol level while the consequent ethrel dipping partially overcome such ripening delay. In addition, the degree of ripening inhibition either during or after the period of ethanol vapor exposure relayed mainly on the concentration of the used ethanol. This was strongly emphasized since fruits of 5% ethanol showed some colour development (Table 2) while those of 10 and 15% ethanol remained almost green throughout the whole 14 days of ethanol vapor exposure (Table 2). During the subsequent storage at ethanol-free air ambient however, ripening delay was also obtained in the fruits of higher ethanol concentration (Table 2). These data also emphasized the previous findings reported by (Saltveit and Sharaf, 1992) that inhibiting tomato fruit ripening using ethanol vapor is reversible.

In terms of fruit softness, no significant differences were obtained among fruits of different ethanol level treatments at each sampling date during the subsequent storage at ethanol-free air ambient which due mainly to ripening inhibition since control fruits were ripen and became significantly softer even by the end of the tow weeks of ethanol vapor treatment and before transferring to ethanol-free air ambient. It is well known that as ripening progressed, fruit became more soft (Atta-Aly and El-Awady, 1993). Therefore, the subsequent ethrel application accelerated fruit ripening (Table 2) and increased the level of fruit softness as compared to those of subsequent water dipped ones (Table 3). In addition, there was a significant increase of fruit softness with extending fruit storage period (Table 3) which entirely due to both ripening development and the longer time of fruit water loss during storage. Hydrolysis enzymes are ethylene dependent (Yang and Hoffman, 1984). Inhibiting ethylene biosynthesis and action with ethanol treatment (Saltveit and Mencarelli, 1988) therefore, may alter the activity of such enzymes and resulted firmer fruits. Such firmness was strongly reduced as fruit reached red-ripe stage (Table 3).

Fruit weight loss, on the other hand, showed low levels of weigh loss during the two weeks of ethanol vapor treatment and did not exceed 1.5% regardless ethanol levels (Table 3). Humidity saturation of the air-flow was the reason behind such low levels of weight loss. During ethanol-free air storage however, fruits followed an ascending order of weight loss as ethanol concentration reduced (Table 3). This may due to fruit ripening delay and subsequently fruit lower permiability. This also may be emphasized by the results presented in Table (3) which indicated that fruits of subsequent ethrel dipping were higher in fruit weight loss than those of water dipped ones at each sampling date. The significant increase in fruit weight loss noticed with extending fruit storage period to reach red-ripe stage due mainly to the longer time of fruit water loss during storage combined with increased fruit permiability as ripening progressed.

It could be also suggested that ethanol inhibited pathogens growth since the percentage of decayed fruits strongly reduced with increasing ethanol level (Table 3). Prolonging the period of fruit storage to reach red-ripe stage may allowed more invasion by pathogens and this may explain the increased level of fruit decay with increasing fruit storage time.

Fruits reached red-ripe stage, which became ready for human consumption, were excluded from the previous analysis and used for quality analysis in terms of LAA, TA and TSS content as well as fruit panel taste. While there were no significant differences among all treatments in terms of fruit content of LAA, there were a pronounced decreases in fruit content of TA and TSS as the level of ethanol exceeds 5 % regardless the subsequent ethrel application (Table 4). The stability of LAA content occurred at red-ripe stage, regardless the levels of previous ethanol vapor or ethrel treatment, may due to equal change in LAA form to either dehydro-ascorbic or gluonic acid due to the positive correlation between ripening and oxidation (Gonzalez and Brecht, 1978). It is well known that sugars and simple acids are the respiration substrates. The longer time of fruit respiration the higher rates of sugars and acids consumption. This may explain the decrease in TA and TSS in the fruits of higher ethanol levels due to the prolonged time between maturation and ripening (Table 4). Fruits of 15 % ethanol which showed the highest TSS and TA reduction levels (0.8 and 0.11% reduction, respectively) than those of control (Table 3) and didn't visually reach the deep red colour (Table 2) of red-ripe stage (hardly passed light-red colour stage) were the only fruits showing the significant reduction in panel taste (Fig 3 and 4). Fruits of 10 % ethanol which were comparable to control fruits in panel taste (Fig 3 and 4) were lower in TSS and TA content but only by about 0.5 and 0.08%, respectively, and were also able to reach the deep colour of red-ripe stage (Table 2). It seems that human taste can sense taste differences in tomatoes if the reduction in TSS and TA exceeds 0.5 and 0.08%, respectively. Furthermore, fruit panel taste doesn't due only to acids and sugars contents but rather to more factors such as aromatic compounds as well as sugar / acid ratio.

It could be concluded that exposing mature-green tomato fruits to ethanol vapor using 5 % ethanol solution strongly delayed fruit ripening, while an almost ripening block was obtained at higher ethanol levels (10 and 15% ethanol) throughout the whole 14 days of ethanol vapor exposure. Such inhibition was eliminated when fruits moved to ethanol-free air which indicated that tomato fruit ripening inhibition using ethanol vapor is reversible. It was also indicated that ethanol vapor application strongly delay the subsequent tomato fruit ripening. After the period of ethanol vapor exposure, dipping in ethrel for 10 sec partially enhanced tomato fruit ripening. Fruit quality and panel taste of ethanol vapor treated fruits were comparable to those of control with or without consequent ethrel application if ethanol concentration in the air-flow passing solution was 10% or less. In addition, ethanol application arrested pathogens growth and strongly reduced the percentage of decayed fruits.

It could be recommended, therefore, that ethanol vapor can be used in a dynamic air-flow system to block or delay fruit ripening especially those sensitive to chilling injury i.e. tomatoes. Such system can be easily used without refrigeration during exportation since such ripening block or inhibition can be reversed by ethanol-free air exposure or by subsequent ethrel application. Ethylene gas can be also used in such air-flow system, after the termination of ethanol vapor exposure, to enhance fruit ripening during exportation or at final destination. These findings may resulted successful exportation and/or storage of the chilling sensitive fruits.

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**Table 1.** Effect of dipping harvested mature-green tomato fruits in $H_2O$ (control) or 1000ppm ethrel for 10 sec on fruit ripening speed as well as quality at red ripe stage. Means within each column followed by the same letter are not statistically different according to Duncan's multiple range test ($P<0.05$).

| Fruit treatment | Days to reach red-ripe stage | % * fruit weight loss | Fruit softness[X] at mature-green stage | Fruit softness at red-ripe stage | LAA [Y] at red-ripe stage | %TA [Z] at red-ripe stage | %TSS at red-ripe stage |
|---|---|---|---|---|---|---|---|
| Control | 19.5 a | 5.64 a | 0.54 a | 1.02 a | 7.18 a | 2.08 a | 4.5 a |
| Ethrel | 12.0 b | 5.46 b | 0.52 a | 1.22 b | 7.03 a | 1.99 a | 4.44 a |

* The percentage of fruit weight loss was measured based on the time required for the fruits to reach red-ripe stage.

[X] Fruit softness was measured as fruit deformation in mm.

[Y] LAA = L-ascorbic acid as mg\100 g fruit fresh tissues.

[Z] % TA = Titratable acidity.

**Table 2.** Effect of exposing harvested mature-green tomato fruits to ethanol vapor for 14 days followed by dipping in $H_2O$ or 1000ppm ethrel for 10 sec on the subsequent fruit colour development (ripening score) during storage at 14±2°C. Ethanol vapor was carried by an air-flow previously passed through solutions of 0, 5, 10 or 15% ethanol before enriching the fruit ambient. Means within each row in each ethrel level followed by the same letter are not statistically different according to Duncan's multiple range test ($P<0.05$).

| Days after ethanol vapor exposure | $H_2O$ | | | | Ethrel | | | |
|---|---|---|---|---|---|---|---|---|
| | Ethanol concentration | | | | Ethanol concentration | | | |
| | 0 % | 5 % | 10 % | 15 % | 0 % | 5 % | 10 % | 15 % |
| 0 | 4.7 a | 3.2 b | 1.5 c | 1.1 d | 4.9 a | 3.1 b | 1.5 c | 1.1 d |
| 4 | 5.0 a | 3.8 b | 2.0 c | 1.4 d | 5.0 a | 4.2 b | 2.4 c | 1.6 d |
| 8 | _* | 5.0 a | 2.8 b | 1.7 c | _ | 5.0 a | 3.9 b | 2.0 c |
| 12 | _ | _ | 3.8 a | 2.1 b | _ | _ | 5.0 a | 2.6 b |
| 16 | _ | _ | 5.0 a | 2.6 b | _ | _ | _ | 3.0 |
| 20 | _ | _ | _ | 3.1 | _ | | _ | 4.3 |
| 24 | | | | 4.3 | | | | |

* Fruit passed red-ripe stage.

**Table 3.** Effect of exposing harvested mature-green tomato fruits to ethanol vapor for 14 days followed by dipping in $H_2O$ or 1000ppm ethrel for 10 sec on the subsequent fruit softness (fruit deformation in mm), % of fruit weight loss and % decayed fruits during storage at 14±2°C. Ethanol vapor was carried by an air-flow as previously described in Table (2). Fruits passed red-ripe stage were excluded and means within each raw in each parameter followed by the same letter are not statistically different according to Duncan's multiple range test ($P<0.05$).

| Sampling Time | Fruit * dipping | Ethanol Concentration ** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 % | 5 % | 10 % | 15 % | 0 % | 5 % | 10 % | 15 % | 0 % | 5 % | 10 % | 15 % |
| | | Fruit softness (mm) | | | | % fruit weight loss | | | | % fruit decay | | | |
| Initial [X] | --------- | 0.39 a | 0.42 a | 0.45 a | 0.42 a | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 0 [Y] | --------- | 0.86 a | 0.87 a | 0.85 a | 0.86 a | 1.3 a | 1.4 a | 1.5 a | 1.5 a | 10.8 a | 6.7 b | 2.5 c | 0.0 d |
| 7 [Z] | $H_2O$ | _*** | 1.24 a | 1.19 a | 1.07 a | _ | 3.7 a | 2.8 b | 2.3 c | _ | 13.3 a | 9.8 b | 0.0 c |
| | Ethrel | _ | 1.29 a | 1.25 a | 1.21 a | _ | 3.9 a | 3.6 a | 3.1 b | _ | 15.3 a | 10.0 b | 6.7 c |
| 14 [Z] | $H_2O$ | _ | _ | 1.62 a | 1.68 a | _ | _ | 7.0 a | 5.3 b | _ | _ | 12.0 a | 8.4 b |
| | Ethrel | _ | _ | 1.97 a | 1.89 b | _ | _ | 8.7 a | 7.8 b | _ | _ | 14.2 a | 12.6 b |
| 21 [Z] | $H_2O$ | _ | _ | _ | 1.9 | _ | _ | _ | 12.1 | _ | _ | _ | 16.7 |
| | Ethrel | _ | _ | _ | 2.22 | _ | _ | _ | 13.1 | _ | _ | _ | 16.3 |

* Fruit dipping was carried out immediately after ethanol vapor exposure and before storing the fruits at 14±2°C.

** Ethanol concentration in the air-flow passing solution.

*** Fruit passed red-ripe stage.

[X] Initial = Immediately after harvesting and before ethanol vapor exposure.

[Y] 0 = Immediately after the 2 weeks of ethanol vapor exposure.

[Z] Storing days at 14±2°C.

**Table 4.** The residual effects of ethanol vapor treatment at mature-green stage for 14 days followed by dipping in $H_2O$ or 1000ppm ethrel as previously described in Table (2) on the subsequent tomato fruit content of L-ascorbic acid (LAA mg \ 100 fruit fresh tissue), titratable acidity (% TA) and total soluble solids (%TSS). Fruit analysis were carried out when fruits reached red-ripe stage. Means within each measured parameter followed by the same letter are not statistically different according to Duncan's multiple range test ($P<0.05$).

| Ethanol concentration | LAA | | % TA | | % TSS | |
|---|---|---|---|---|---|---|
| | $H_2O$* | Ethrel* | $H_2O$ | Ethrel | $H_2O$ | Ethrel |
| 0 % | 7.21 a | 7.16 a | 0.51 a | 0.51 a | 4.80 a | 4.80 a |
| 5 % | 6.84 a | 6.92 a | 0.45 bc | 0.47 ab | 4.65 a | 4.65 a |
| 10 % | 6.86 a | 6.69 a | 0.42 cd | 0.45 bc | 4.20 bc | 4.45 b |
| 15 % | 6.58 a | 7.08 a | 0.39 d | 0.40 cd | 3.90 d | 4.10 cd |

- Fruit dipping treatment.

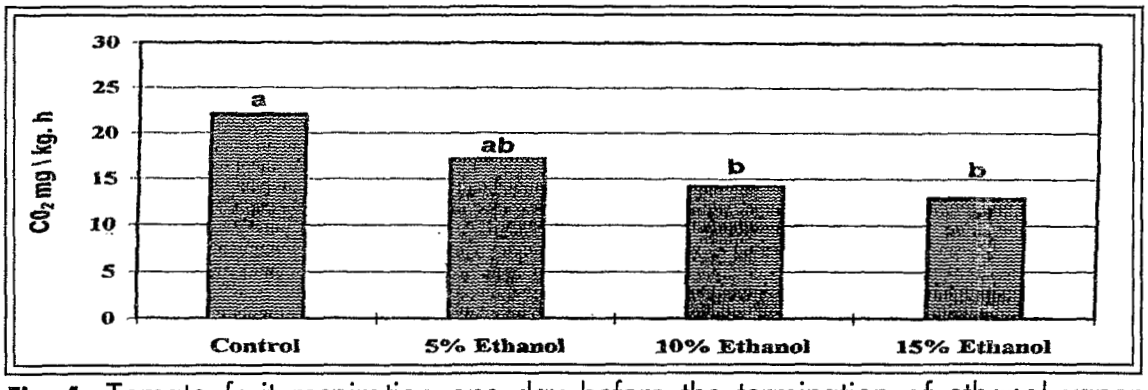


**Fig. 1.** Tomato fruit respiration one day before the termination of ethanol vapor exposure at $14\pm2^{o}C$. Fruits were harvested at mature-green stage and exposed to ethanol vapor carried by an air-flow system for 14 days as previously described in Table (2). Means separation according to Duncan's multiple range test ($P < 0.05$).

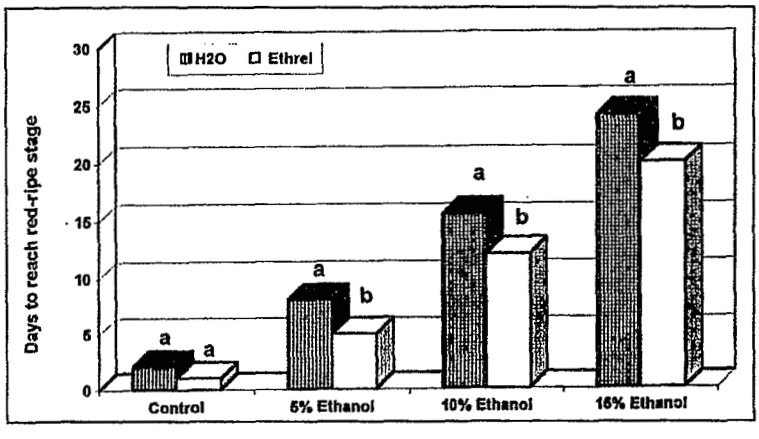


**Fig. 2.** Effect of exposing harvested mature-green tomato fruits to ethanol vapor for 14 days followed by dipping in $H_2O$ or 1000ppm ethrel for 10 sec on the subsequent days required for the fruits to ripen during subsequent storage at

14±2°C. Ethanol vapor was carried by an air-flow system as previously described in Table (2). Means separation, at each ethanol level, according to Duncan's multiple range test ($P < 0.05$).

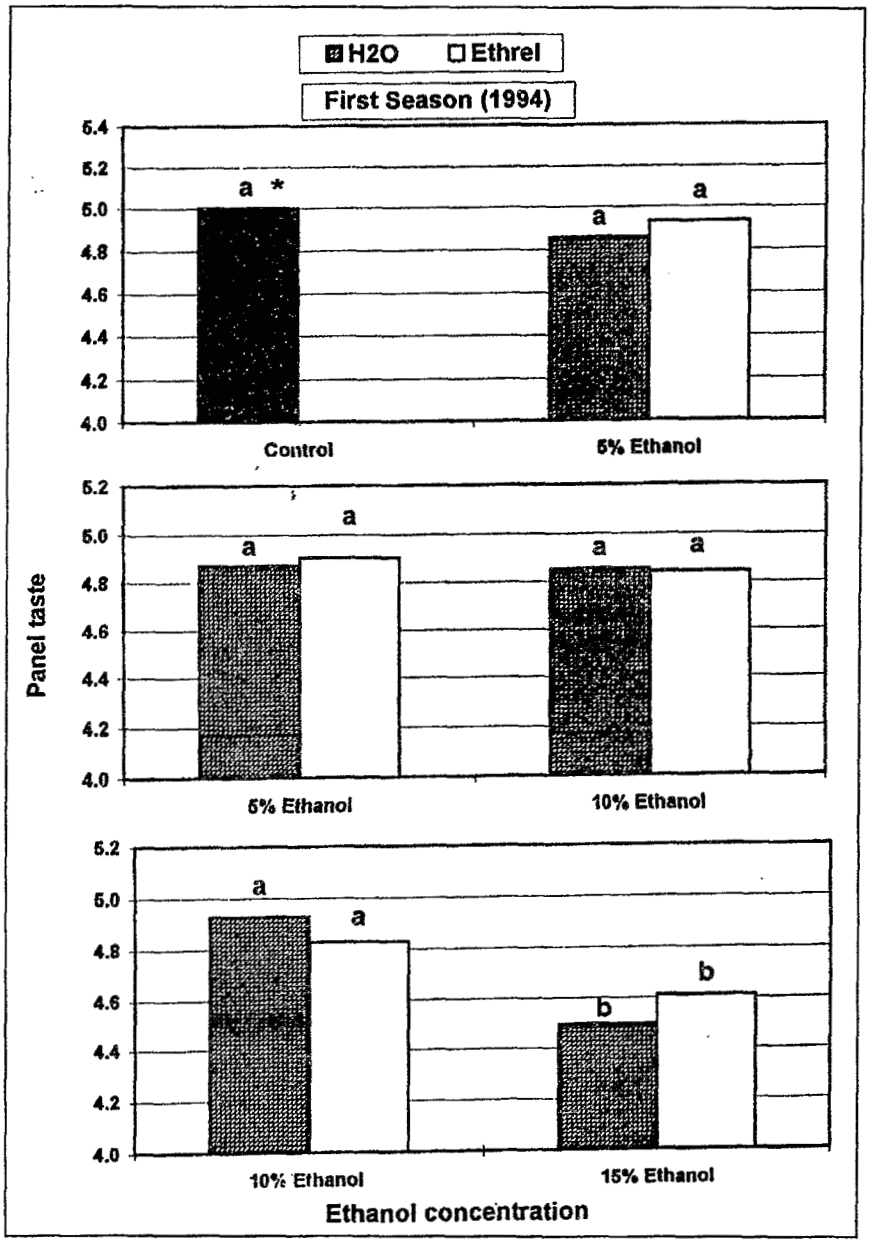


**Fig. 3.** Effect of exposing harvested mature-green tomato fruits to ethanol vapor for 14 days followed by dipping in $H_2O$ or 1000ppm ethrel for 10 sec before storing at 14±2°C, as previously described in Table (2), on the supsequent fruit panel taste. Due to the remarkable delay in fruit ripening with increasing ethanol concentration, fruits of each two close treatments which ripen in close time were exposed to panel taste together. *Control fruits (0 % ethanol) were almost at light-red stage by the end of ethanol vapor treatment and didn't receive ethrel. Means separation, at each two close ethanol levels, according to Duncan's multiple range test ($P < 0.05$).

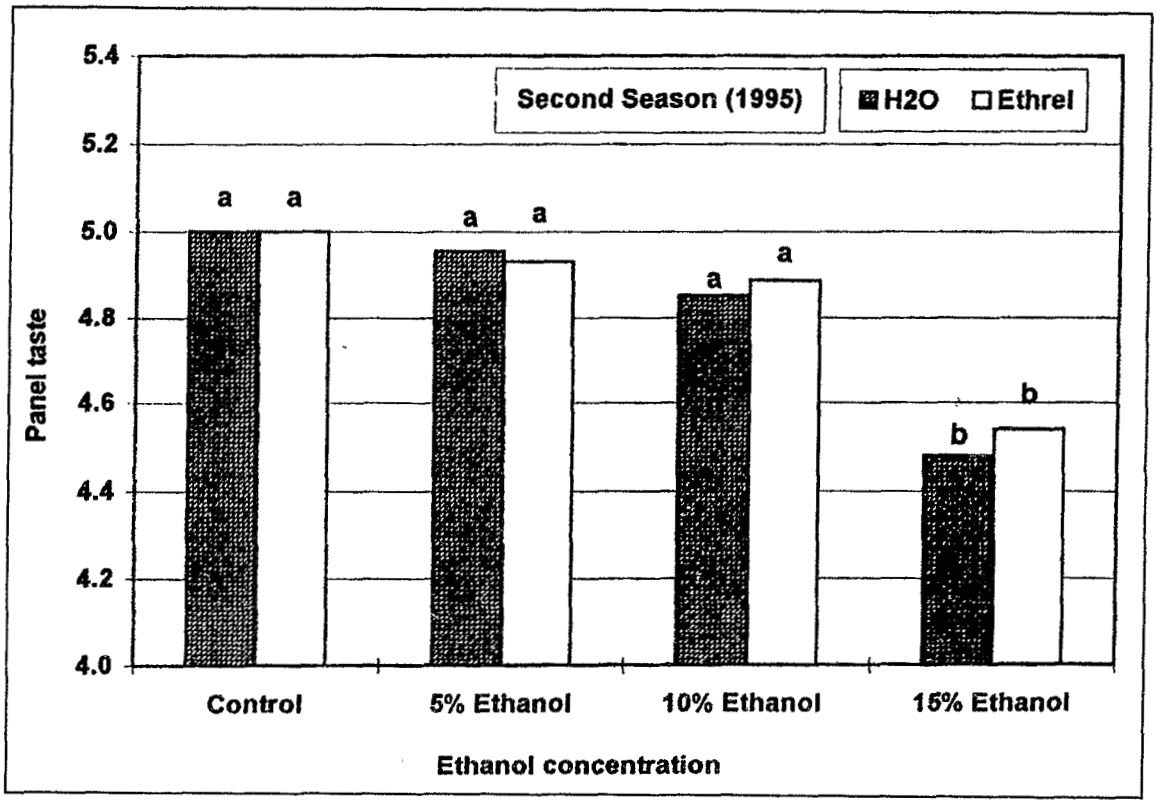


**Fig. 4.** Effect of exposing harvested mature-green tomato fruits to ethanol vapor for 14 days followed by dipping in $H_2O$ or 1000ppm ethrel for 10 sec before storing at 14±2°C, as previously described in Table (2), on the subsequent fruit panel taste. Due to the remarkable delay in fruit ripening with increasing ethanol concentration, fruits were harvested and introduced to the air-flow system (ethanol vapor) in a subsequental time-table to obtain ripe fruits from all treatments in one day for accurate panel taste analysis. Means separation according to Duncan's multiple range test ($P< 0.05$).

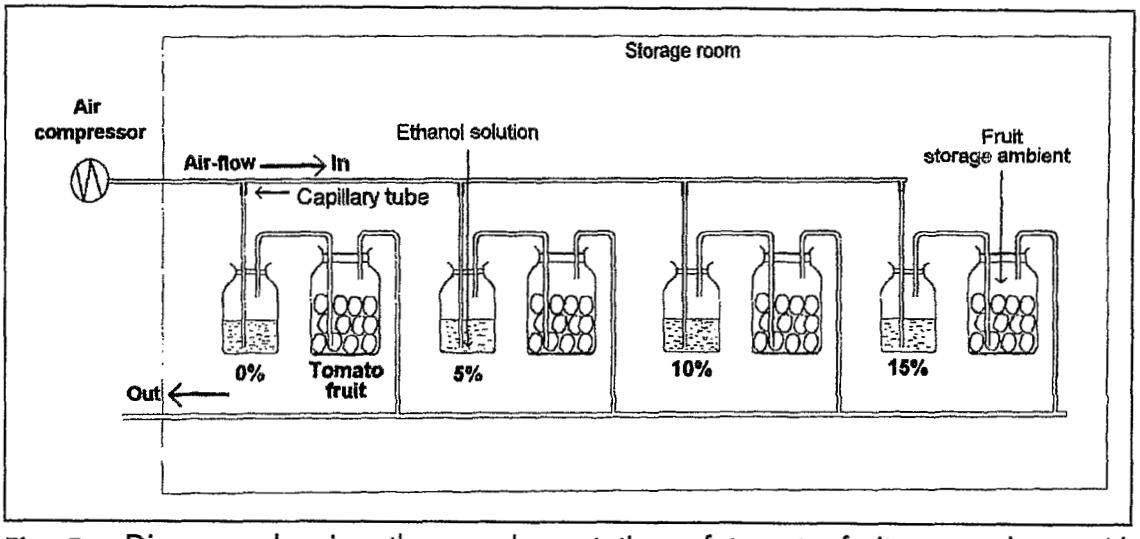


**Fig. 5.** Diagram showing the supplementation of tomato fruit atmosphere with ethanol vapor through a dynamic air-flow system.