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Non Inhibition of Ripening in Hot Air Treated Tomato (*Lycopersicon esculentum* Mill) Fruits

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Abstract: Mature green tomato fruits were subjected to hot air treatment variously for 1-5 min at 60, 70 and 80°C. The fruits were then stored in sterile desiccators at 30°C and 100% relative humidity and observed for colour development and reduction in chlorophyll content as indicators of ripening. The general appearance of fruits was also noted. Results obtained show that heat treatment enhanced ripening without serious adverse effect on the general appearance of fruits. Colour development was noticed in some heated fruits on the first day in storage but was delayed in control till day 5. Fruits heated for 4-5 min at 60°C, 2-4 min at 70°C and 3 min at 80°C all ripened to stage 5. The fruits that ripened best were those treated for 2 min at 70°C and 3 min at 80°C. All other time-temperature combinations resulted into ripening to various extents with most ripening more than the control. Fruit injury in form of transluscent patches was moderate in fruits treated for 5 min at 80°C and that was the most serious adverse effect observed. There was no significant difference in the rate of colour development between heated and control fruits once it commenced.

Key words: Colour development, ripening, heat treatment, noninhibition, hot air

INTRODUCTION

Tomato, a perishable climacteric fruit ripens within a few days after attaining maturity whether detached from the parent or not. The appearance of bright red colour due to lycopene a carotenoid, disappearance of green colour due to chlorophyll degradation, increased ethylene production and softening are ripening related processes in tomato fruits (Yoshida *et al*., 1984). The main bulk of tomato production in Nigeria is in the North, while major consumption occurs in the Southern part of the country. As a result, there is usually a time lag of about 5-8 days between harvest and purchase by final consumers. During this period, no form of treatment or special storage is given the commodity. This has led tomato producers in the country to harvest fruits at the mature green or breaker stage rather than the red-ripe stage to reduce losses due to overripening with the attendant increased susceptibility to decay pathogens.

Various postharvest treatments that maintain fruit quality and reduce losses due to pathogens have been investigated (Mohammed and Sealy, 1986; Bhowmik and Pan, 1992; Fallik *et al*., 1994; Mari *et al*., 1996; Nigro *et al*., 1998). Various degrees of success have been reported for heat treatment alone as hot air, vapour heat, solar radiation and hot water dip, or in combination with other methods (Klein and Lurie, 1990; Jacobi and Wong, 1992; Sams *et al*., 1993; Jacobi *et al*., 1996; Fallik *et al*., 1996; Afek *et al*., 1999). Heating tomatoes before storage was reported to be effective in controlling decay by fungi (Fallik *et al*., 1993; Aborisade and Ojo, 2004).

Most researches on prestorage heat treatment of tomatoes have however focused on storage life at 0-20°C after heating (Fallik *et al*., 1993; Lurie *et al*., 1996). Heating has also been done mainly between 34.5 and 50°C for 8-166 h (Paull, 1990). Aborisade and Ojo (2002) however reported that high temperature short time treatment for 1-5 min at 70°C controlled *Rhizopus stolonifer* decay of

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mature green Roma-VF cultivar of tomatoes stored at 30°C after treatment in a ten day storage trial. As yet, there are no reports on the effect of such treatment on ripening and general appearance of treated fruits.

Thermal injury of heat treated fruits is observed as skin scald which may appear as transluscent or brown or black areas on fruit, excessive water loss, delayed, abnormal or slow ripening or failure of fruits to ripen at all (Klein and Lurie,1990; Paull, 1990; Lurie *et al*., 1993; Iwahashi *et al*., 1999).

As follow up to earlier study by Aborisade and Ojo (2002) on the effectiveness of heating mature green tomato fruits at 60 and 70°C in controlling *R.stolonifer* decay, this study was designed to investigate the effect of this same treatment on ripening and general appearance of fruits during storage for ten days. Colour development and chlorophyll degradation were used as indices of ripening.

MATERIALS AND METHODS

Sample Source and Preparation

Healthy mature tomato fruits cv. Roma-VF of uniform green colour and similar size were selected for the study. The fruits were harvested from a commercial farm at Ikota village in Ondo State of Nigeria. The fruits were wiped with soft tissue paper (Fallik *et al*., 1993). Individual fruits were labelled and placed in sterile Petri plates of 5 cm diameter.

Treatment

Fruits were subjected to hot air treatment in a Gallenkamp oven. The treatment was done separately for 1-5 min at 60, 70 and 80°C, all at 1 min intervals. Control fruits were not exposed to hot air. After treatment, the fruits were immediately transferred into sterile desiccators over sterile water which provided an atmosphere of 100% relative humidity inside the desiccator.The desiccators were placed on the side bench in the laboratory at 30±2°C. Treatment was done within 3 h of harvest and each treatment had five replicates.

Colour Rating and Chlorophyll Content

Tomato fruits were observed daily for colour changes. Colour development was classified into one of six categories:

1 = Completely green
2 = Green to tannish yellow, traces of red not more than 10% surface area (breaker)
3 = Orange to red, greater than 10% but not more than aggregate of 30% (turning)
4 = Orange to red, greater than 30% aggregate but not more than 60% surface area
5 = >60% red but not more than 90% surface
6 = >90% surface area red.

Chlorophyll content was determined six days after heat treatment. Two grams of pulped sample was extracted with 30 mL 80% acetone and left for 24 h at 4°C. The absorbances of the extracts were then measured at 645 and 663 nm. Total chlorophyll content was calculated using the following formula (Mackinney, 1941).

$$\text{Total chlorophyll} = 20.2\,(A_{645}) + 8.02\,(A_{663}) \times \frac{V}{1000 \times W}$$

Where
A = Absorbance
W= Weight of sample extracted
V= Final volume (cm^3) of extract

Weight Loss and Heat Injury Assessment

Treated fruits and untreated controls were individually assessed for weight loss at 0 and 10 days of storage. This was expressed as percentage of the original weight.

Heat injury was assessed 24 h after heat treatment and identified as transluscent areas on fruits. The severity was subjectively ranked from 1-5.

No injury = ranked 1;
Slight = about 5% aggregate ranked 2;
Moderate = about 20% but not more than 30% aggregate ranked 3
Severe = > 30% but not more than 50% aggregate ranked 4;
Very severe = > 50% aggregate ranked 5.

Data Analysis

Data obtained were subjected to analysis of variance and the means were separated by New Duncan's Multiple Range test (NDMR). Rates of skin colour development were determined by fitting linear regression between colour ratings of 2 and 4 (the linear portion of the sigmoidal colour development curve of visual colour rating) against time in replicates of treatments whose mean colour rating reached a minimum of 5.0. The slopes of these regression lines were taken to correspond to rates (Jacobi and Wong, 1992).

RESULTS

Signs of colour break appeared one day after treatment in a few treated fruits but the means did not differ significantly from the control which had not changed (Table 1). More fruits reached the breaker stage on the second and third days of storage with some already progressing towards the turning stage on day 3. The means of some treatments on both days were significantly different from the control which had still not changed from green. Treatment for 4 and 5 min at 60°C had means of 2.40±0.40 and 2.60±0.20 respectively on day 3 of storage. Fruits heated for 1 and 3 min at 60°C, 1 and 5 min at 70 and 80°C were still green like the control.

Four days post treatment, all treated fruits except those for 1 min at 60°C had started ripening. Colour development was fastest in those treated for 4-5 min at 60°C with means of 3.40±0.40 each. This trend was maintained till eight days post-treatment. Colour development was observed for the first time in control on day 5 of storage. By day 5, colour development in fruits heated at 60°C for 5 min was at a mean of 4.40±0.40. On day 10, those treated for 4 min at the same temperature ripened to a mean of 5.60±0.24 on day 10. Fruits treated for 2 min at 70°C, 3 min at 80°C ripened to a mean of 5.80±0.20 and those for 4 min at 70°C ripened to a mean of 5.40±0.40. Control fruits ripened to a mean of 4.40±0.60 on day 10. All fruits that ripened to stage 5 can be considered ripe enough. Statistical analysis showed that control fruits were significantly different from treated fruits in the first 4 days after treatment. On the 10th day, control fruits were still slightly significantly different from fruits treated for 4-5 min at 60°C, 2-4 min at 70°C and 3 min at 80°C. The slowest to develop colour were those treated for 1 min at 60°C, 1 and 5 min at 80°C. These fruits had means of 3.20±0.66, 3.40±0.68 and 3.00±0.84, respectively (Table 1). The rate of colour development was however not significantly different between control and treated fruits (Table 2) but colour development was generally enhanced in treated fruits compared to controls.

Total chlorophyll content in treated fruits was generally less than untreated on the 6th day after treatment. Only those treated for 4 min at 60°C and 5 min at 80°C had more chlorophyll than the control (Table 3).

Table 1: Mean colour rating of tomato fruits exposed to hot air at different temperatures for different lengths of time and subsequently stored at 30°C

Temp. (°C)	Time (min)	Day 1	Day 2	Day 3	Day 4	Day 5
	Control	1.00±0.00^{a}	1.00±0.00^{a}	1.0±0.00^{a}	1.00±0.00^{a}	1.80±0.20^{abcd}
60°	1	1.00±0.00^{a}	1.00±0.00^{a}	1.00±0.00^{a}	1.00±0.00^{a}	1.20±0.20^{ab}
	2	1.00±0.00^{a}	1.00±0.00^{a}	1.20±0.20^{ab}	1.60±0.40^{ab}	1.80±0.58^{abcd}
	3	1.00±0.00^{a}	1.00±0.00^{a}	1.00±0.00^{a}	1.20±0.20^{ab}	1.40±0.40^{ab}
	4	1.00±0.00^{a}	1.60±0.24^{ab}	2.40±0.40^{cd}	3.40±0.40^{cd}	4.40±0.40^{ef}
	5	1.40±0.00^{a}	1.80±0.49^{b}	2.60±0.24^{d}	3.40±0.40^{cd}	4.40±0.40^{ef}
70°	1	1.00±0.00^{a}	1.00±0.00^{a}	1.00±0.00^{a}	1.40±0.24^{ab}	1.60±0.40^{abc}
	2	1.20±0.00^{a}	1.40±0.40^{ab}	1.40±0.40^{ab}	1.80±0.58^{ab}	2.20±0.58^{abcd}
	3	1.40±0.00^{a}	1.40±0.40^{ab}	1.80±0.49^{abcd}	2.40±0.68^{bc}	2.60±0.60^{abcd}
	4	1.00±0.00^{a}	1.00±0.00^{a}	1.20±0.20^{ab}	2.20±0.58^{abc}	2.40±0.60^{abcd}
	5	1.00±0.00^{a}	1.00±0.00^{a}	1.00±0.00^{a}	2.40±0.24^{bc}	3.00±0.45^{cde}
80°	1	1.00±0.00^{a}	1.00±0.00^{a}	1.00±0.00^{a}	1.40±0.24^{ab}	1.60±0.40^{abc}
	2	1.20±0.00^{a}	1.40±0.40^{ab}	1.60±0.40^{ab}	2.40±0.51^{bc}	2.80±0.58^{bcd}
	3	1.20±0.00^{a}	1.40±0.40^{ab}	1.40±0.40^{ab}	2.20±0.49^{abc}	3.20±0.58^{de}
	4	1.00±0.00^{a}	1.00±0.00^{a}	1.20±0.20^{ab}	2.00±0.32^{ab}	2.80±0.49^{bcd}
	5	1.00±0.00^{a}	1.00±0.00^{a}	1.00±0.00^{a}	1.80±0.20^{ab}	2.20±0.37^{abcd}

Figures are means of five replicates±SE of the mean Means followed by the same letter(s) in the same column are not significantly different by New Duncan's Multiple Range Test (p>0.05)

Table 1: Continued

Temp. (°C)	Time (min)	Day 6	Day 7	Day 8	Day 9	Day 10
	Control	2.20±0.37^{abc}	2.80±0.37^{abc}	3.20±0.49^{abc}	3.60±0.68^{abcd}	4.40±0.60^{abcde}
60°	1	1.20±0.20^{a}	1.60±0.24^{a}	2.00±0.32^{a}	2.40±0.51^{a}	3.20±0.66^{ab}
	2	2.20±0.58^{abc}	2.80±0.66^{abc}	3.40±0.60^{abcd}	3.40±0.60^{abcd}	4.00±0.63^{abcde}
	3	1.60±0.60^{ab}	1.80±0.58^{a}	2.00±0.77^{a}	2.80±0.58^{ab}	3.60±0.40^{abcd}
	4	4.60±0.51^{ef}	5.00±0.32^{de}	5.40±0.24^{e}	5.60±0.24^{e}	5.60±0.24^{e}
	5	4.60±0.51^{ef}	4.66±0.51^{cde}	4.80±0.49^{cde}	4.80±0.49^{cde}	5.00±0.55^{bcde}
70°	1	1.80±0.37^{abc}	2.60±0.51^{ab}	2.60±0.51^{ab}	3.40±0.58^{abcd}	4.20±0.58^{abcde}
	2	2.80±0.58^{abcd}	3.20±0.37^{abcd}	4.00±0.55^{bcde}	4.80±0.20^{cde}	5.80±0.20^{e}
	3	2.600.68^{abcd}	3.20±0.49^{abcd}	4.00±0.45^{bcde}	4.60±0.24^{bcde}	5.20±0.37^{cde}
	4	3.00±0.68^{bcde}	3.20±0.37^{abcd}	4.00±0.32^{bcde}	4.40±0.51^{bcde}	5.40±0.40^{de}
	5	3.20±0.49^{bcde}	3.40±0.60^{abcd}	3.60±0.75^{abcde}	3.60±0.75^{abcd}	3.60±0.75^{abcd}
80°	1	2.00±0.45^{abc}	2.60±0.68^{ab}	2.60±0.68^{ab}	3.20±0.73^{abc}	3.40±0.68^{abc}
	2	3.20±0.66^{bcde}	3.20±0.66^{abcd}	3.40±0.68^{abcd}	3.80±1.22^{abcde}	4.00±0.89^{abcde}
	3	4.20±0.58^{def}	4.40±0.51^{bcde}	4.80±0.49^{cde}	5.20±0.37^{de}	5.80±0.20^{e}
	4	3.40±0.68^{cde}	3.80±0.86^{bcde}	4.20±0.92^{bcde}	4.20±0.92^{abcde}	4.40±0.20^{abcde}
	5	2.60±0.60^{abcd}	2.80±0.73^{abc}	3.00±0.84^{abc}	3.00±0.84^{abc}	3.00±0.84^{a}

Figures are means of five replicates±S,E of the mean Means followed by the same letter(s) in the same column are not significantly different by New Duncan's Multiple Range Test (p>0.05)

Table 2: Rate of colour change in heat treated tomatoes stored at 30°C

Treatment			
Temp (°C)	Time (min)	Rate	SD
Control		0.5144	0.0360
60	4	0.5556	0.0628
60	5	0.4951	0.0854
70	2	0.5717	0.0163
70	3	0.4553	0.0748
70	4	0.5060	0.0720
80	3	0.5782	0.0960

Ripening reached the maximum colour rating of 5.80 obtained in this study in fruits heated for 2 min at 70°C. At this treatment also, there was no fruit decay. At 80°C for 3 min also, mean colour rating reached 5.80 on day 10 but one fruit decayed on day 9 due to *Fusarium* after it had attained stage 6 of colour development. Some fruits decayed by *Fusarium* sp or *Botrytis cinerea* after ripening to stages 4 and 5. Some fruits exposed for 4 and 5 min at 80°C also decayed but this same set were also the most injured by the heat treatment (Table 4). Decay by moulds occurred first on day 6 in a few

Table 3:Total chlorophyll content of tomato fruits six days after hot air treatment and in storage at 30°C

Treatment		
Temp (°C)	Time (min)	Total chlorophyll content (mg g^{-1})
Control		0.0785
60	1	0.0714
	2	0.0406
	3	0.0364
	4	0.1259
	5	0.0726
70	1	0.0323
	2	0.0246
	3	0.0615
	4	0.0582
	5	0.0067
80	1	0.0621
	2	0.0215
	3	0.0241
	4	0.0111
	5	0.0808

Table 4: Mean ratings of heat injury on mature green tomato fruits exposed to hot air at different temperatures for varying lengths of time 24 h after treatment

Temperature (°C)	Exposure period (min)	Severity of heat injury
Control		1.00±0.00^{a}
60	1	1.00±0.00^{a}
	2	1.00±0.00^{a}
	3	1.00±0.00^{a}
	4	1.60b±0.24^{a}
	5	1.60±0.40^{ab}
70	1	1.00±0.00^{a}
	2	1.00±0.00^{a}
	3	1.00±0.00^{a}
	4	1.20±0.20^{a}
	5	2.60±0.24^{cd}
80	1	1.00±0.00^{a}
	2	1.00±0.00^{a}
	3	1.00±0.00^{a}
	4	2.20±0.20^{bc}
	5	3.20±0.58^{d}

Figures are means of five replicates ± S.E of the mean. Means followed by the same letters in the column are not significantly different by New Duncan's multiple range test ($p>0.05$)

Table 5: Percentage weight loss in tomato fruits exposed to hot air at different temperatures for different lengths of time and then stored at 30°C and 100% RH

Treatment		%Weight loss immediately	%Total weight loss 10days
Temp (°C)	Time (min)	after treatment	in storage
Control		0.0000±0.00	2.7354±0.41^{abcd}
60	1	1.0420±0.27^{abcd}	3.3057±0.7978^{abcd}
	2	0.6960±0.28^{abc}	2.0203±0.1658^{a}
	3	1.9760±0.39^{d}	2.4254±0.3532^{abcd}
	4	1.0160±0.27^{abcd}	2.7378±0.1028^{abcd}
	5	1.3480±0.35^{cd}	3.6250±0.5802^{d}
70	1	0.6720±0.31^{abc}	2.9682±0.1846^{abcd}
	2	0.6120±0.25^{abc}	2.2645±0.3042^{abc}
	3	0.8240±0.56^{abc}	2.6258±0.3904^{abcd}
	4	0.2380±0.23^{ab}	3.3000±0.3888^{bcd}
	5	0.7960±0.32^{abc}	2.7196±0.2312^{abcd}
80	1	1.2920±0.20^{bcd}	1.9218±0.2023^{a}
	2	0.1700±0.17^{a}	2.3166±0.2343^{abc}
	3	0.6140±0.26^{abc}	2.0496±0.2200^{ab}
	4	0.3640±0.22^{abc}	2.5128±0.1881^{abcd}
	5	0.9380±0.28^{abc}	2.5211±0.435^{abcd}

Figures are means of five replicates ± S.E of the mean. Means followed by the same letters in the same column are not significantly different by New Duncan's multiple range test ($p>0.05$)

of the fruits treated at 60 and 80°C after they had reached advanced stages of colour development. There was no heat injury on fruits heated 1-3 min at 60, 70°C and 80°C. There was slight to moderate injury on fruits treated for longer periods at the three temperatures. The most severely injured were those heated for 5 min at 80°C (Table 4).

Weight loss immediately after treatment was between 0.17 and 1.97%. Greater weight loss occurred in fruits treated for 3-5 min at 60°C and 1 min at 80°C (Table 5). Statistical analysis showed slightly significant difference between control and a few treatments. Total weight loss by day 10 was between 1.92 and 3.62%. There was no shriveling in any of the fruits.

DISCUSSION

This investigation has shown that holding mature green tomato fruits in hot air for 1-5 min at 60, 70 and 80°C did not inhibit ripening but rather enhanced colour development at certain time-temperature combinations within a ten day post-treatment period. This is contrary to earlier reports that heat treatment inhibited ripening (Paull, 1990; Fallik *et al*., 1993). Previous investigations however, were treatments below 60°C for long periods and storage at 0-20°C. The time of exposure was found to be significant in this study. Exposure for 4-5 min at 60°C and 2-4 min at 70 and 3 min at 80°C significantly enhanced ripening. The tomatoes that ripened best were those treated for 2 min at 70°C and 3 min at 80°C. Treatment within the same range was also reported to effectively control tomato decay by *R. stolonifer* (Aborisade and Ojo, 2002). Although no data is here presented on incidence of decay during post-treatment storage at 30°C, it is significant that decay by *Fusarium* and *Botrytis cinerea* common pathogens on tomato fruits was controlled to some extent at this same time-temperature range. This is the first report of non inhibition and no delay of ripening in tomato fruits that were heat treated. Lurie *et al*. (1996) reported that ripening related processes were inhibited in tomatoes during heating but recovered afterward during storage at 20°C. Torres *et al*. (2006) reported that high temperature and solar irradiance caused photo-oxidative stress in detached immature tomato fruits and this may possibly interfere with the oxidative reactions in ripening processes. Klein and Lurie (1990) earlier reported that 'Granny Smith' apples held for 4 days at 38°C before storage at 0°C for 4 months were yellower than the controls. The high temperatures employed in this study might have been sufficient to quickly increase the rate of some biochemical processes in the fruits resulting into earlier initiation of colour development. This early initiation was observed at the three temperatures even on the first day after treatment while it was delayed in control till the fifth day of storage by which time, the fruits heated at 60°C were almost completely red. Some heated fruits however ripened slowly and did not develop colour beyond the controls. These were fruits heated for 1-2 min at 60°C, 1 min at 70°C, 1 and 5 min at 80°C. This suggests that the holding time of 1 min was not sufficient for any serious effect while the longer time of 5 min especially at 70 and 80°C resulted in heat injury which interfered with normal ripening processes. Attainment of full ripening may be possible after hot air treatment of tomato fruits for 2 min at 70 and 3 min at 80°C if given more time. Although total chlorophyll content did not exactly correspond with the pattern of colour development, the lesser chlorophyll content in treated fruits in comparison with control on day 6 of storage supports the evidence of enhanced ripening obtained from colour ratings during storage after the heat treatment employed in this study.

The general appearance of heated fruits did not differ from non heated fruits except those heated longest at the three temperatures employed in this study which showed some heat injury. The highest weight loss of 3.62% observed on day 10 also did not result in shriveling of the fruits.

The results of the present study therefore indicate that prestorage hot air treatment for few minutes at temperatures from 60°C has the advantage of non inhibition of ripening of Roma-VF tomato fruits in addition to decay control. Further studies are underway to determine how heating at the time-

emperature combinations employed presently affects specific physiological and biochemical processes associated with tomato fruit ripening and nutrient status. This is necessary for possible application of the various time-temperature regimes for prolonging postharvest life of tomato fruits.

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