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Research Article

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Effects of Biochar Produced at Different Pyrolysis Temperatures and Storage Environment on Ripening and Quality Characteristics of Tomatoes

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Abstract Tomatoes were exposed to each type of biochar pyrolysed at 300°C, 400°C and 500°C, and the control treatment had no biochar. The tomatoes were ripened in three environments namely the refrigerator set at 10°C, oven set at 25°C and laboratory desktop at room temperature. The effect of environment was significant ($p<0.05$) on visual colour and tomatoes in the open air recorded highest colour score, implying that they ripened faster, than tomatoes in incubator and refrigerator. Tomatoes stored with biochar had significantly higher visual colour scores than tomatoes without biochar and this meant that tomatoes with biochar ripened faster than those without biochar. Tomatoes stored in open air required a lower force to penetrate than tomatoes in refrigerator and incubator. Tomatoes not treated with biochar required greater force to penetrate than tomatoes with biochar, meaning untreated tomatoes ripened slower than treated tomatoes. Total soluble solids (TSS) was not affected ($p>0.05$) by both the ripening environment and biochar pyrolysis temperature. Titratable acidity (TA) was affected ($p<0.05$) by environment, tomatoes in open air ripened faster than tomatoes in incubator and fridge. Biochar treated tomatoes had a higher TSS/TA ratio, implying they were ripening faster, than untreated tomatoes. Contrary to the fact that biochar can be used to increase shelf life of tomatoes, results from the experiment showed that biochar increased ripening suggesting that freshly made biochar from maize cobs may contain ethylene that accelerated ripening. The ethylene content seemed to be dependent on the pyrolysis temperature, hence the pyrolysis temperature*ripening environment interaction recorded on some of the ripening parameters.

Keywords Biochar, pyrolysis, ethylene, tomatoes, ripening, environment

Introduction

Tomato (*Solanum lycopersicum*) is one of the most important high value vegetable crops grown around the world. It is consumed as a fresh or processed product. More consumers have developed increased interest towards tomato-based products due to the high nutritional value and potential health benefits of tomato [1]. Tomatoes contribute to a well-balanced, healthy diet; with the right proportions of vital nutrients such as minerals, vitamins, essential amino acids, sugars, lycopene and other carotenoids and dietary fibres [2].

After growth and harvesting of the fruit, it is noteworthy that tomato is highly perishable due to its nature as a climacteric fruit, and thus cannot be stored for long periods of time. As a climacteric fruit, it is characterized by high ethylene production and high respiration rates at the onset of ripening [3]. Ethylene makes the fruit palatable, on one side, but it contributes to compositional changes, senescence and deterioration of the fruit. Due to lack of information on appropriate post harvest technologies such as packaging, temperature management and post harvest treatments, post harvest losses of tomato can be considerable. Efforts from research have seen an increase in the production of tomato fruit, but maximum profits can only be realized when there are similar efforts to minimize post harvest losses and to increase its shelf life [4].

Besides tomato being a climacteric fruit, the perishability of tomato fruit is worsened by late harvesting, injuries due to rough handling and lack of pre-cooling facilities and proper storage infrastructure. These are amongst the many other challenges fruit and vegetable traders face when dealing with tomatoes. Both qualitative losses which results in quality reduction and consequently, the value of the food item and quantitative losses which results in weight reduction and consequent loss in total value needs to be minimized. These losses need to be reduced so that traders may realize reasonable a profit which is the primary goal of every business [5] and also contribute immensely to economic growth and poverty reduction in the country [4]. However, a range of methods that are used to preserve tomatoes require high energy sources (e.g refrigeration) and are not available and affordable to most poorly resourced traders in Zimbabwe [5].

In view if this challenge, this research aims to determine a method for adoption by resource poor traders to reduce postharvest losses of tomatoes. Instead of purchasing ripening or ripened tomatoes from the farmers or any suppliers it is perceived that trader could reduce losses by purchasing mature tomatoes which are not easily injured or bruised during transportation and storage then later ripen them at their convenience. The product for ripening the green mature fruits is Biochar. Biochar, a product of pyrolysis of biomass products, is an alternative and cheap method that can be used by tomato traders to generate ethylene for ripening fruits and vegetables. Biochar produced from fresh parent materials is known to generate ethylene. As far as the researchers could ascertain from literature search, no studies have been carried out to investigate the generation of ethylene from biochar to ripen tomatoes in various environments, by biochar pyrolysed at different temperatures.

Materials and Methods

Experimental details

Tomatoes (Tengeru variety) at breaker stage with almost the same weight and without defects, were harvested early in the morning from Glen Lurca Farm (-17.70° latitude and 30.83° longitude) in Zvimba District of Mashonaland West Province, Zimbabwe. The tomatoes were ferried in a 24 litre cooler box, in the same morning, to Post Harvest laboratory at Chinhoyi University of Technology. The tomatoes were cleaned with distilled water and wiped dry using a paper towel, each tomato fruit then packed in a 20 cm × 17 cm polythene sealable bag. Single fruits were packed to avoid excessive oxygen consumption and carbon dioxide accumulation, which can affect ethylene metabolism according to [6].

Figure 1: Tomatoes used for the incubation with biochar

Maize cobs were used as the feed materials for the pyrolysis in the making of the biochar. The harvested cobs were sun dried for seven days and were later ground with a hammer mill fitted with an 8 mm screen. The ground cobs were stored for 14 days under shade, in a dry place and later fed to the kiln for pyrolysis. The kiln was fired for six hours at different temperatures (300°C, 400°C and 500°C) and composition of pyrolysed materials emerged completely carbonized. The kiln was then left to cool for one hour and the pyrolysed cobs were collected and packed in sealable polythene bags.

The post harvest parameters of fruit ripening that were used are total soluble solids (TSS), penetrability, titratable acidity (TA) and sugar acid ratio, and were done in accordance to Organisation for Economic Co-operation and Developmet (OECD, 2003) standards and guidelines. The tests were done before and after incubation of tomatoes with biochar. At each interval the bags were allocated numbers and selection was done using random number tables. 10% of tomato fruits was picked as a sample of 200 tomatoes and were used to determine maturity of the fruits before storage.

Experimental design

The experiment was set up as 4×3 factorial in a randomized complete block design and replicated three times. The treatments with regard to the type of biochar as one factor were as follows;

Trt 1: biochar produced at pyrolysis temperature of 300 ^{o}C

Trt 2: biochar produced at pyrolysis temperature of 400 ^{o}C

Trt 3: biochar produced at pyrolysis temperature of 500 ^{o}C

Trt 4: control, without biochar

Five grams of each type of biochar, measured with a Shimadzu UW6200H analytic balance, was placed in plastic sealable bags containing one tomato fruit and the control treatment had no biochar.

The other factor for determination was the ripening environment for the tomatoes, were as follows;

T_{re}: 520L Kelvinator refrigerator set at 10±2 ^{o}C,

T_{in}: 400L Scientific 298D incubator set at 25 ^{o}C

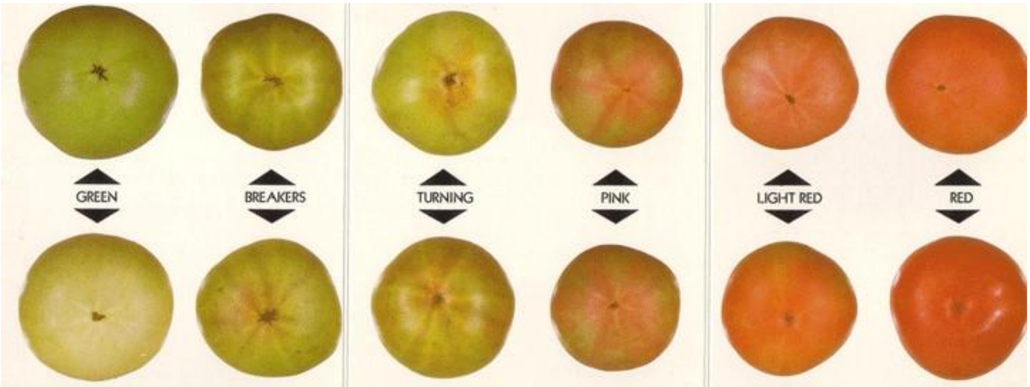
T_{rm}: Laboratory desktop at room temperature.

Five plastic sealable bags with each type of biochar and with no biochar were placed in each block and therefore there were a total of 180 sealable plastic bags in the experiment. Measurements were taken on tomatoes from the five sealable bags per block per treatment and the mean was used in analysis of variance (ANOVA).

Data collection

Data was measured and collected for the following parameters;

Colour Tests: The colour changes during tomato fruit storage were measured at 5 days interval for 25 days using the USDA colour classification chart for grades of fresh tomatoes (Figure 2).



The ripening stages were assigned numbers for easy analysis of results:

Breaker-1, Turning-2, Pink-3, Light Red-4 and Red-5.

Figure 2: Tomato Colour Classification Chart (Source: USDA [7])

Penetrability: Flesh firmness was measured for tomatoes using a hand held penetrometer (Effegi) equipped with an 8 mm plunger. The results were expressed in kilogram force (kgf).

Total Soluble Solids (TSS): Two longitudinal slices were taken from each fruit and each slice was squeezed separately in a longitudinal way. TSS (°Brix) in the juice was determined, from the fruit, with a Reichert LCD digital bench refractometer in 0.1% graduations, calibrated using distilled water to give a zero reading.

Titratable Acidity (TA): TA was estimated by titration of tomato juice extracted during TSS with 0.1 M NaOH. Phenolphthalein indicator was used to determine the end point. All results were recorded to one decimal place and percent acidity as citric acid was calculated using Equation 1 and the sugar/acid ratio using Equation 2.

Titratable acidity (g/l) = $\frac{ml\ NaOH\ \times M\ (NaOH)\times acid\ meq.factor}{ml\ Juice\ Titrated} \times 100$ (1)

Where,

acid meq. factor used was 0.0064.

The sugar acid ratio = $\frac{°Brix\ value}{Percentage\ \ acid}$ (2)

Data Analysis

The data was analyzed statistically using Analysis of Variance (ANOVA) technique with GenStat version 12 software. Comparison of treatment means was done using the Least Significance Difference (LSD), at 5% significance level. The means on interaction diagrams were separated using ± standard error of the difference when interaction effects were significant at P<0.05.

Results and Discussion

Tomato Visual Color

Data pertaining to tomato visual colour scores was significant (P<0.05) as shown in Fig 3. For tomatoes stored at breaker stage, visual colour score development was not significantly affected (P>0.05) by environment at 5 days after incubation with biochar in all the environments. However, environmental effect on visual colour development was significant (P<0.05) at 10 days after ripening tomatoes. Tomatoes ripened in the open air had a significantly (P<0.05) higher colour score (4.5) than tomatoes in the refrigerator (1.92) and incubator (2.67).

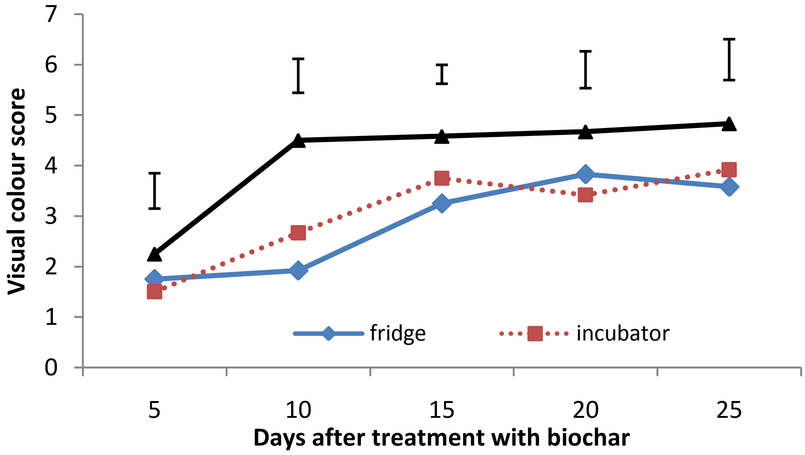


Figure 3: Effect of ripening environment on tomato visual colour

The incubation of tomatoes with biochar pyrolysed at different temperatures was not highly significant (P>0.05) on visual colour development (Fig 4).

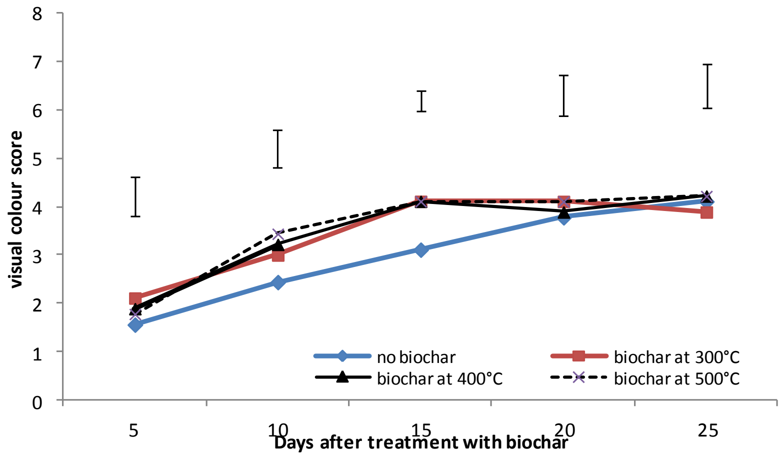


Figure 4: Effect of biochar pyrolysed at different temperatures on tomato visual colour.

Significant (P<0.05) differences on visual colour development were recorded on day 15 on tomatoes with no biochar treatment application. The visual color scores increased from day 5 to day 25 of the experiment. However, the effect of biochar pyrolysed at 300°C, 400°C and 500°C were not significantly (P>0.05) different from each other.

Penetrability

Results regarding the effect of environment on penetrability of tomatoes are shown in Fig 5. The different environments were significant (P<0.05) at 5, 10, 20 and 25 days after treatment application. At day 5 the penetrability force of tomatoes in the open air was lowest at 1.7 kgf while for tomatoes in the incubator and fridge was higher at 3.0 kgf and 2.8 kgf respectively. From day 5 to day 10 the penetrability force of tomatoes in the open air and incubator dropped sharply to 0.77 khf and 1.18 kgf respectively and was steadily decreasing until day 25. From day 10 to 25 tomatoes ripened in refrigerator recorded a higher penetrability force than tomatoes ripened in the incubator and in open air. However, from day 15 to 25 the penetrability recorded for the three environments was not significantly different from each other. Tomatoes ripening in the refrigerator required a greater force to penetrate than tomatoes ripened in the incubator and in open air.

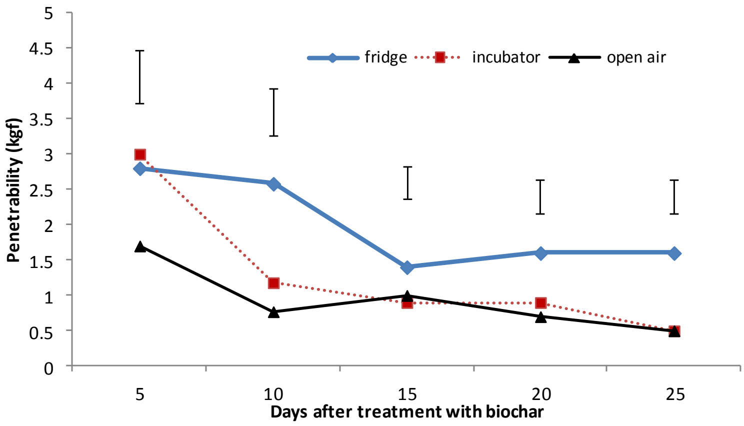


Figure 5: Effect of ripening environment on tomato penetrability

Generally, the penetrability force of the tomatoes was decreasing from day 5 to 25 for all the three biochar treatments and the treatment with no biochar applied. However, the effect of the biochar pyrolysed at different temperature was not significantly (P>0.05) different from each other and the no biochar treatment as well (Fig 6).

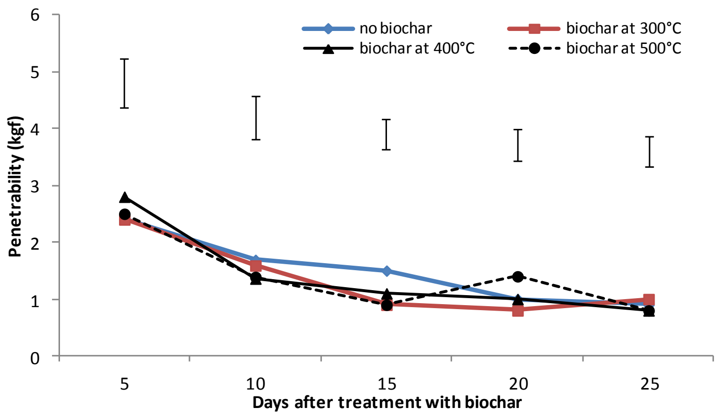


Figure 6: Effect of biochar type on tomato penetrability

Total Soluble Solids (TSS)

Figure 7 shows data regarding the effect of incubation environment on TSS. Results show that there was not significant (P>0.05) differences between the TSS means for the three environments over the duration of the experiment.

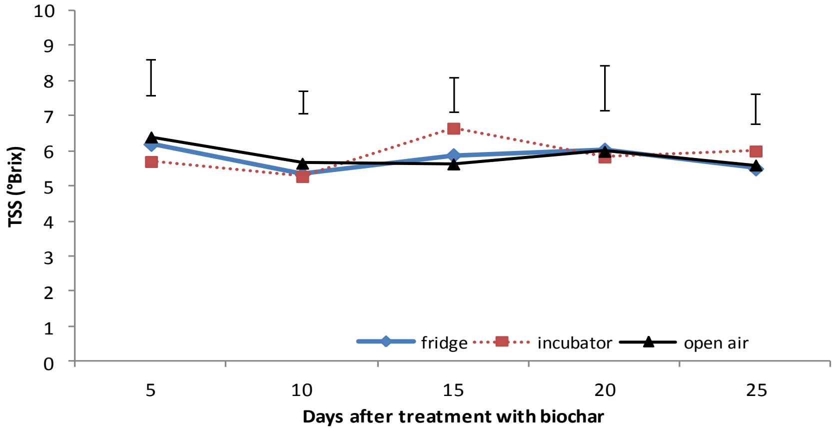


Figure 7: Effect of ripening environment on tomato Total Soluble Solids

Data pertaining to the effect of biochar produced at different pyrolysis temperature on TSS is shown in Fig 8. Results reveal that there was no significant (P>0.05) mean differences on the effect of types of biochar applied at the different environments.

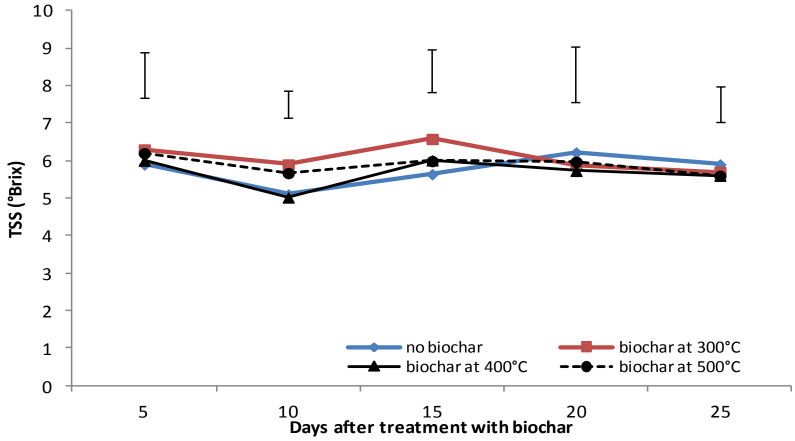


Figure 8: Effect of biochar type on tomato Total Soluble Solids

Titratable Acidity (TA)

Data in Fig 9 shows the effect of the incubation environment on TA in the tomatoes. The environment had a significant (P<0.05) effect on TA in the experiment. Tomatoes from the fridge recorded the highest TA throughout the experiment than those from the incubator and open air. Numerically, the TA in the tomatoes was decreasing from day 5 to day 25.

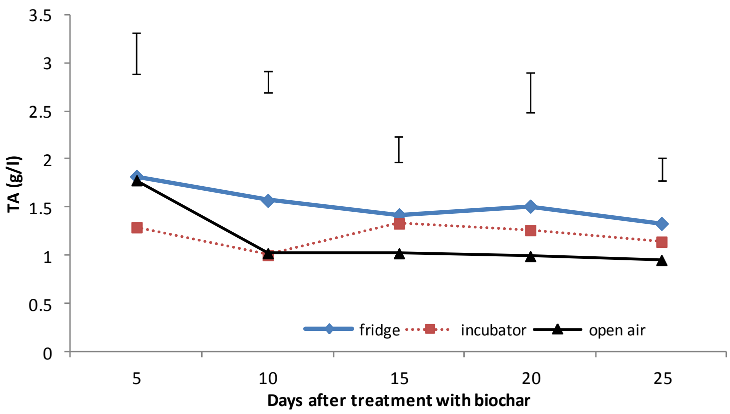


Figure 9: Effect of ripening environment on tomato Titratable Acidity

Fig 10 shows results of the effect of biochar produced at different pyrolysis temperature. Biochar pyrolysis temperature did not have a significant effect (P>0.05) on TA in all the treatment applications.

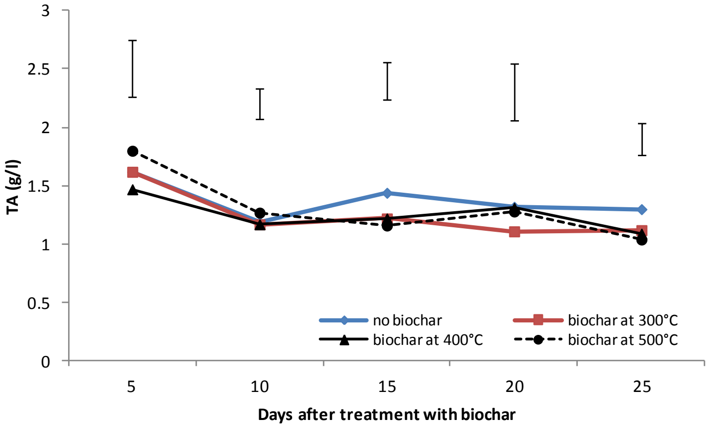


Figure 10: Effect of biochar type on tomato Titratable Acidity

TSS/TA Ratio

Results for the effect of environment on TSS/TA ratio is shown if Fig 11. The effect of environment was significant (P<0.05) on TSS/TA ratio. From day 10, TSS/TA means for open air remained the highest. However, means recorded from the fridge environment were the lowest throughout the experiment.

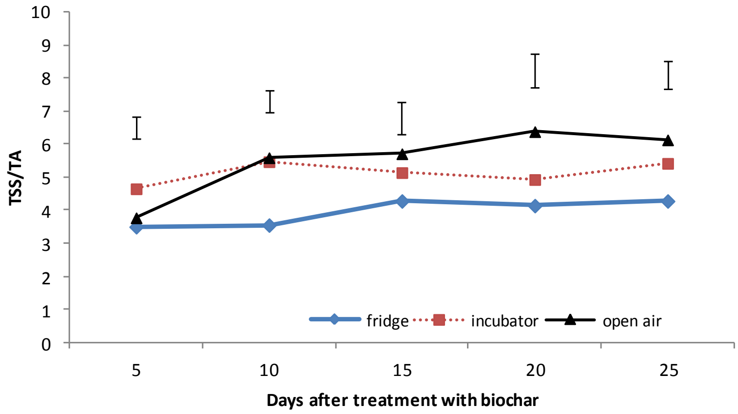


Figure 11: Effect of ripening environment on tomato TSS/TA ratio

Results on effect of biochar type on TSS/TA ratio is shown in Fig 12. Findings reveal that the effect of the biochar was only significant (P<0.05) at day 15 for no biochar treatment which recorded the lowest TSS/TA ratio. However, all the means for the effect of biochar type were not significant (P>0.05) from each other.

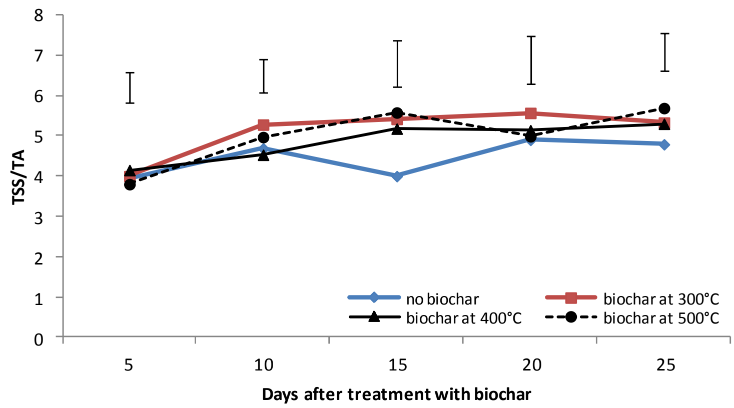


Figure 12: Effect of biochar type on tomato TSS/TA ratio

Discussion

For tomato fruits harvested at breaker stage, environment effect on visual colour development was significant 10 days after ripening tomatoes under three environments. Tomatoes ripened in the open air had a significantly higher colour score than tomatoes in the refrigerator. Tomatoes in incubator did not show significant differences in visual colour score from tomatoes stored in refrigerator 20 days after storage. The effect of low temperature storage is reduction in changes that are associated with ripening, and such changes include colour from green to red [8]. Incubation of tomatoes with biochar pyrolysed at different temperatures did not show significant effect on visual colour development. The effect of biochar was significant on visual colour development at day 15 after treatment of tomatoes with biochar. Tomatoes without biochar had a significantly lower colour score than tomatoes treated with biochar. According to Martínez Romero [9], treatment of fruits with biochar prolongs its shelf life due to ethylene removal. Absence of ethylene results in reduced ripening and senescence. The present study therefore differs from the previous findings and this can be explained by use of freshly made biochar which can be associated with ethylene production [10]. The higher visual colour scores for tomatoes treated with biochar than controls means biochar treated tomatoes ripened faster.

The environment had a significant effect on penetrability, and tomatoes ripened in the refrigerator required a greater force to penetrate than tomatoes ripened in the incubator and in open air. This means that low temperature storage slowed the respiration of the fruit thus reduced ripening which is associated with loss of firmness [11]. Penetrability was not significantly affected by biochar pyrolysis temperature except for when tomatoes without biochar had a significantly lower penetrability. According to Martins [12] , low pyrolysis temperatures for biomass produce an activated carbon like product that has been used to prolong shelf life of fruits and vegetables. However, in this study, tomatoes treated with biochar were easy to penetrate which means they ripened faster than controls. This ripening trend is due to use of freshly made biochar that could have produced ethylene and use of maize cobs as substrate material at lower pyrolysis temperatures [13][14]. The lower penetrability value of tomatoes without biochar was due to absence of exogenous ethylene, which in turn slowed ripening. Ripening causes cell wall disintegration due to breakdown of pectins and polysaccharides that leads to fruit softening and hence higher penetrability [15].

The environment had a significant effect on TA in the experiments and higher TA values were recorded in tomatoes ripened in the refrigerator than in open air. Suslow and Cantwell [16] reported that TA changed slightly on tomatoes stored in refrigerator. High loss of TA in the incubator and open air correlated with increased temperature and led to increased changes related to ripening and senescence. The tomatoes with low TA values might have utilized their acids in metabolic activities of living tissues that depletes organic acids [17].

The effect of environment was significant on TSS/TA ratio with open air recording a higher ratio than refrigerator. The highest sugar to acid ratio for tomatoes ripened in open air is due to increased respiratory activities linked with high temperature [18]. TSS/TA ratio in the fridge was minimum due to low temperatures that reduced respiration and and changes associated with ripening. TSS/TA ratio was not significantly affected by biochar except at day 15 in experiment 1 where tomatoes without biochar had a significantly lower TSS/TA ratio than 300°C, 400°C and 500°C biochars. Tomatoes stored without biochar ripened slowly as compared to fruits treated with biochar due biochar post production conditions, low pyrolysis temperature effect, which affected its quality. The results differ from findings by Zapata *et al.* [19] who found out that biochar treatment increases the shelf life of tomato. Fulton *et al.* [10] found out that biochar not stored in the open air for at least 90 days, after production, produced significant amounts of ethylene. High pyrolysis temperature results in less available carbon and nutrients for microbial activity than in low pyrolysis temperature biochars [20].

Conclusion

According to this study biochar made from maize cobs contain some ethylene that accelerated ripening of tomatoes. The amount of ethylene in biochar is influenced by the temperature at which the biochar is made. Pyrolysis of maize cobs at low temperatures (300°C) results in more ethylene produced by the biochar as evidenced by high ripening rates in biochar treated tomatoes. Tomatoes treated with biochar had higher colour scores, high penetrability (lower force needed to penetrate them), lower titratable acidity and higher TSS/TA ratios than untreated tomatoes. TSS was not significantly affected by biochar pyrolysis temperature. A significantly lower TA value was recorded when tomatoes were treated with 300°C biochar and ripened in incubator which suggest more ethylene effect and high temperature effect on ripening of tomatoes. A higher TSS/TA value was recorded in 400°C treated tomatoes and ripened in open air which indicates more ripening properties of 400°C biochar.

Fruit and vegetable traders are advised to buy mature tomatoes and transport them before they start to ripen in order to reduce postharvest losses. They then will have to ripen their tomatoes at their convenience using freshly made biochar from maize cobs pyrolysed at 300°C to 500°C as this increases ripening. However, there is need for further studies to determine the ethylene content of freshly made biochar from maize cobs to confirm observations in this study.

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