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Evaluation tomato quality (*Solanum lycopersicum*) at three different ripening stages using viscometry

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ABSTRACT

The quality of tomato (*Solanum lycopersicum*) was investigated at green (GR), yellowish–orange (YOR) and red ripening (RR) stages using viscometry, to identify the best ripening stage to maximally derive its nutritional values. Selected tomatoes were obtained from a local market in Osogbo, Nigeria at three ripening stages They were cleaned, grated, extracted with muslin cloth and centrifuged. The viscosity of the supernatant - fresh tomato juices (FTJ) was measured with an Ubbelohde viscometer and recorded on an hourly basis for 48 h. The data were analyzed with SPSS. The study established that the viscosity of FTJ ranged from 1.39 to 2.25 cP (GR > YOR > RR), but reduced at the first twelve hours of study and ranged from 1.12 cP (RR) to 1.65 cP (GR). At the last twelve hours of study, the viscosity of the three juices remained fairly constant and ranged from 1.12 to 1.24 cP (RR < YOR < GR). However, the levels of overall reduction observed in viscosities of the FTJ monitored for 48 h were 44.89% (GR), 19.46% (YOR) and 19.42% (RR), indicating poor quality retention in GR tomato. Thus, it is more nutritionally suitable to consume yellowish-orange and red ripen tomatoes.

Introduction

Tomato, scientifically called *Solanum lycopersicum* has its origin in Central and South America, but it is now grown throughout the year in various parts of the world for commercial purposes and can be bought from a supermarket and farmer's market (local market). Globally, in 2014, the tomato was grown on 5 million hectares of land to yield 17 million tons of tomatoes, with the Peoples Republic of China and India being the major producing countries (FAOSTAT, 2017). This plant is also grown to be exported to different countries. For example, in Bangladesh, 100 thousand tons of it was harvested in an area of 13000 hectares (BBS, 2007). This plant can be cultivated in various geographical zones and can be perennial or semi-perennial, but commercially it is considered annual (Geisenberg and Stewart, 1986).
Botanically, it is a fruit from the nightshade family. These fruits are cultivated in various colours like red, yellow, green, orange, pink, white and purple and vary in sizes and shapes which include round, oval, cherry but all have the same nutritional characteristics (Vaughan and Geissler, 1997). From a nutritionist's point of view, tomato is a vegetable. It is the world's most consumed vegetable, due to its state as a basic ingredient in a large variety of raw, cooked or processed foods. The vegetable is often added to drinks, pasta dishes, salads and pizzas. The vegetable is rich in useful micro-and macro elements (such as potassium, phosphorus, magnesium, iron, chlorine, sulphur, zinc, boron, manganese, calcium and copper), vitamins (A, B, C, K and H) and anti-oxidants. Tomatoes are harvested at different ripening maturity stages: green ripening stage, half ripening stage and red ripening state. During the process of ripening, chlorophyll is degraded and yellow-orange carotenoid and red lycopene are synthesized (Boe et al., 1968). The synthesis of these pigments is light and temperature dependent (Kaymas and Surmali, 1995;

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Khudairi, 1972). Proper harvesting at different ripening stages determines the nutrient content as well as storage durability of the fruit. The fruit contains a large quantity of water (95%), while the remaining 5% consists mainly of carbohydrates and fibres.

The presence of anti-oxidants in tomatoes reduces the risk of developing heart disease, high blood pressure, cataracts, asthma and cancer such as lung, stomach, cervical, prostate, oral, breast, pancreatic, colorectal, ovarian and many other types of cancer (Blum et al., 2005). Tomato, when consumed as juice is a good sports drink that restores athletes from fatigue and sleepiness and is also a good energy drink that rejuvenates the health of patients on dialysis (Debjit et al., 2012) Tomato is an excellent vegetable for rapid skin cell replacements (Freeman and Reimers, 2010). The advantages of these fruits include their availability to people of all ages and cultures, cost-effectiveness and availability in many forms.

Several methods are available in evaluating the quality of foods. For instance, Differential Absorbance Technique has been used to determine quality parameters such as hue angle, chlorophyll contents, titratable acidity and firmness of tomatoes (Rahman et al., 2019). In addition, viscometry has been used in food industries to evaluate the quality of milk (Kumbar and Nedomova, 2015), beer-wort (Krstanovi et al., 2019), and hydrocolloid (Abbas et al., 2010), but it has been rarely used to determine different ripening stages of tomatoes.

The viscosity of fluid is the resistance to its flow (Eiteman and Goodrum, 1993) and arises from the direct motion of molecules past each other and the transfer of momentum. Viscosity is a direct measurement of fluid quality. A change in viscosity can indicate a fundamental change in the material under test (Rao, 1997). Viscosity has been considered as one of the quality parameters used in assessing available tomato paste brands sold in Kano markets (Ndife et al., 2020). In addition, viscosity was one of the physicochemical parameters considered by Hassen et al. (2019) during the evaluation of effects of pre-heating and concentration temperature on the quality of semi-concentrated tomato (*Solanium lycopersium*) paste.

As a result of the advantages and health benefits of tomatoes to humans coupled with variation in its nutrients based on variation in ripening stages, it is, therefore, essential to determine its quality at different ripening stages. This paper reports on the viscosity dependence of the quality of tomatoes juices at three different ripening stages to identify the best stage for its consumption and to maximize its nutritional values.

Theory

The measurements of the viscosity of a liquid can be classified into two viz; one in which the rate of flow is through the capillary tube, and the second involves the measurement of the rate of descent balls in the liquid. The former is based on the Poiseuille law and the latter is based on the Stokes equation. Capillary viscometers are relatively simple and inexpensive pieces of glassware. Examples of this type of viscometer include Ostwald capillary and Ubbelohde capillary viscometer also called Suspended Level Viscometer. Ubbelohde capillary viscometer is the modified version of Ostwald and is used in this study (see Fig. 1). To use it to measure viscosity, the reservoir is filled with the desired liquid and sucked to the timing bulb through the capillary tube while the venting tube is covered. Because of the height difference (h), there is a hydrostatic head or driving pressure that produces the flow that the liquid experiences in the capillary or in the narrow diameter section of the viscometer. The time it takes the liquid to flow from point M_1 to point M_2 is then measured. In other words, the time it takes the desired volume of liquid between M_1 and M_2 to flow through the capillary.

Flow of a Newtonian fluid through a capillary is relatively easy to analyze. Ignoring kinetic energy terms, the time is proportional to the solution viscosity through the following relation:

Using the rate of stress and strain, Tritton (1988) and Faber (1995) gave the equations of a viscous force (F) for flow of an incompressible fluid in a non - rotating frame as:

$$\frac{F}{V} = \frac{\partial}{\partial x_i}\left[\eta\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)+\lambda\delta_{ij}\nabla.\,u\right] \quad (1)$$

$$= \frac{\partial}{\partial x_i}\left[\eta\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}+\frac{2}{3}\delta_{ij}\nabla.\,u\right)+\mu_B\lambda_{ij}\nabla.\,u\right] \quad (2)$$

where λ is second viscosity coefficient, μ_B = bulk viscosity, δ_{ij} = Kronecker delta, η = dynamic viscosity and $\nabla.\,u$ = divergence, while Einstein summation is used to sum over j = 1, 2 and 3. For an incompressible fluid $\nabla.\,u = 0$ and λ term drops out.

Assuming η to be constant in space, equation (2) then becomes a vector form given by

$$\frac{F_{viscous}}{V} = \eta\ \nabla^2 u \quad (3)$$

∇^2 u is the Laplacian vector. Two other forces acting on fluid parcels are

$$\frac{F_{viscous}}{V} = -\nabla P \quad (4)$$

where P is the pressure and

$$F = \frac{F_{body}}{V} \quad (5)$$

Equations (3), (4) and (5) are added together and the result is equated to the Newton's law for fluids to yields

$$\rho \frac{\partial u}{\partial t} + u . \nabla u = -\nabla P + \eta \nabla^2 u + F \quad (6)$$

where ρ is density of the liquid.

Birds *et al.* (1965) divided equation (6) by ρ to get Navier-Stokes equation

$$\frac{\partial u}{\partial t} + u . \nabla u = -\frac{\nabla P}{\rho} + \upsilon \nabla^2 u + \frac{F}{\rho} \quad (7)$$

where $\upsilon = \frac{\eta}{\rho}$= Kinematic viscosity.

Sutera and Skalak (1993), and Polyenin *et al.* (2002) further simplified equation (6) for irrotational, incompressible flow by putting F = 0 to give

$$\rho \frac{\partial u}{\partial t} = -\nabla P + \eta \nabla^2 u + \rho g \quad (8)$$

where $\frac{\partial}{\partial t}$is the mass derivative and g = acceleration due to gravity. For steady incompressible flow

$$\frac{\partial u}{\partial t} = 0 \quad (9)$$

So, equation (8) now becomes

$$\eta \nabla^2 u = \nabla P + \rho g \quad (10)$$

But the flow is through a capillary (circular cross-section) and so the flow pattern is then reduced to the Hagen-Poiseuille flow. This gives the exact solution of the Navier- Stoke's equation as

$$\eta \nabla^2 u = \nabla P \quad (11)$$

But for a cylindrical tube of length L and radius R, the equation of flow in axial direction takes the form

$$\frac{d^2 u}{dt^2} + \frac{1}{r}\frac{du}{dr} = \frac{\Delta P}{\eta L} \quad (12)$$

where r is defined in the range 0 < r < R and ΔP is the pressure difference between two points of distance L apart.

y application of no-slip condition at the wall of the tube, the solution of equation (11) is

$$V = \frac{R^2 \Delta P}{4 \eta L}\left[1 - \left(\frac{r}{R}\right)^2\right] \quad (13)$$

Then the volume flow rate Q is then

$$Q = \frac{V}{t} 2\pi \int_0^R V(r)\, r\, dr \quad (14)$$

Equation (14) leads to the Poiseuille formula

$$Q = \frac{\pi R^2 \Delta P}{8 \eta L} \quad (15)$$

where R and L are the radius and length of the capillary, respectively.

With equation (15) we can determine the viscosity by measuring the volume flow rate. The solution of equation (14) leads to the Poiseuille law upon which capillary viscometers operating principle is based. According to the Poiseuille law, the liquid volume V passing at time t by a capillary of radius R and length L under the pressure difference ΔP is equal

$$V = \frac{\pi R^2 \Delta P t}{8 \eta L} \quad (16)$$

where

$$\Delta P = (h_2 - h_1) \rho g \quad (17)$$

is the hydrostatic pressure difference between points M_1 and M_2 and $h = h_2 - h_1$ is the difference in liquid levels, ρ = liquid density and g = acceleration due to gravity.

Measurement of many parameters in equation (15) is affected by measurement error, so if the time of flow for standard liquid (e.g., water) of known viscosity is t_w and the tested liquid t_x and we know that $V_w = V_X$, then it is possible to calculate the viscosity of the tested fluid from

$$\eta_X = \eta_W \frac{\rho_X t_X}{\rho_W t_W} \quad (18)$$

Materials and methods

Collection of samples of tomatoes and extraction of their juices

Fresh tomatoes at green (GR), yellowishorange (YOR) and red (RR) ripening stage were bought at a local market in Osogbo, Nigeria. They were cleaned with distilled water and air-dried. About ten tomatoes of average size were selected from each ripening stage. The tomatoes for each ripening stage were grated, the juice was extracted with a muslin cloth (10 µm) and centrifuged (4000 x g, 15 min), followed by flow time determination with an Ubbelohde viscometer.

Description of the Ubbelohde Viscometer and measurement of viscosity

The Ubbelohde viscometer (Fig. 1) is a u-shaped piece of glassware with a reservoir on one side and a measuring bulb with a capillary on the other side. The Ubbelohde device has a third arm (pressure equalization arm) extending from the end of the capillary and opening to the atmosphere. In this way, the pressure head only depends on a fixed height and no longer on the total volume of liquid. The Ubbelohde viscometer was used in this study because of its advantages over the Ostwald viscometer (speed, accuracy within + 0.1%), small sample size (about 11 mL is sufficient), low susceptibility to errors and cost-effectiveness. For the kinetic energy term of the flow to be ignored and for accurate results, the flow time of the viscometer was adjusted so that it was greater than 100 sec. Therefore, the used viscometer was fabricated at the glass blow unit of the Department of Chemistry, University of Ibadan, Nigeria, such that the flow time for water was 120 sec.

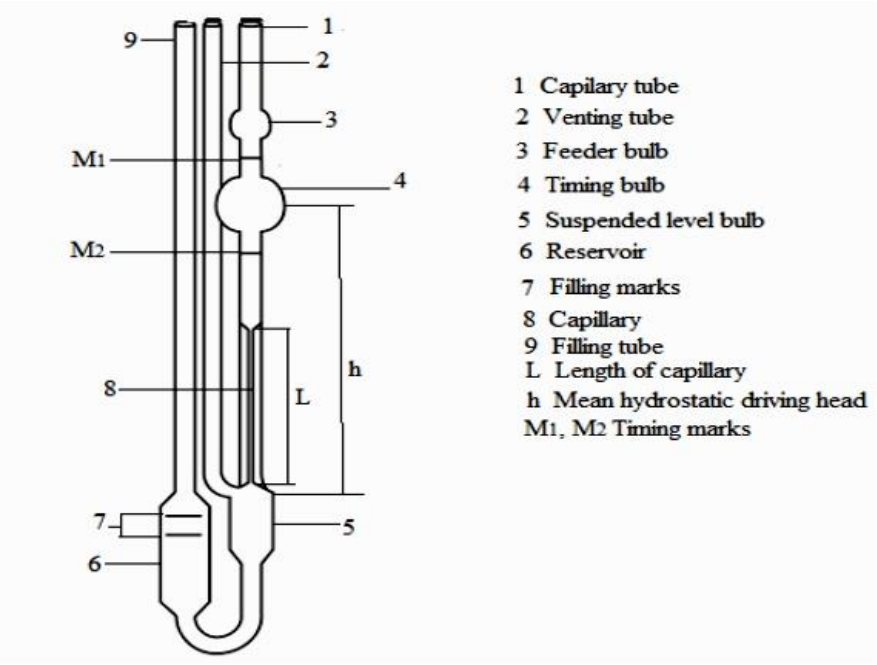

Fig. 1. Ubbelohde viscometer

Prior to the determination of the flow time of the tomato juice, the flow time of deionized water was measured using the Ubbelohde viscometer. Eleven millimetres (11 mL) of the solvent (water) was carefully transferred into the lower reservoir of the viscometer with a measuring cylinder and equilibrated in a water bath at 25 ± 5 °C for 10 min. The water was sucked with a vacuum pump to the timing bulb (4) through the capillary tube (1), with the venting tube (2) covered with a finger. After the solvent had passed the indicator mark (M_1) to the feeder bulb (3), the capillary tube was closed and the meniscus of the water was adjusted to be on M_1 (above the timing bulb). A stopwatch was then used to measure the flow time between the two etched marks M_1 and M_2. The flow time was repeated thrice and averaged. Subsequently, flow time for each of the extracted juices was continuously recorded on an hourly basis for forty-eight hours (48 h). The average flow time for each ripening stage was compared with the average flow time of water (equation 18) to determine the viscosity (Ƞ) of the tomato juices in cent- poise (cP). The viscosities of the tomato juices determined in this study at the three different ripening stages (green,

yellow-orange and red) were correlated with the quality parameters such as fruit skin colour, tissue firmness, chlorophyll contents, ascorbic acid, total soluble solids (TSS), titratable acidity and pH previously determined by Rahman et al. (2019).

Statistical Analysis

All analyses were carried out in triplicates. Data were subjected to descriptive statistics (IBM SPSS Statistics 20). Means were separated using Duncan's (1955) multiple range test. Significant differences were established at $P \leq 0.05$.

Results and Discussion

The time versus viscosity plots of tomato juices at three ripening stages are shown in Fig. 2. The highest viscosities recorded in the three ripening stages differed and decreased proportionally with time. Higher viscosity was observed in green (GR), when compared with yellowish–orange (YOR) and red (RR) ripening stages of tomatoes. On the other hand, Table 1 and Table 2 show the variation of viscosity with respect to time for the first twelve (1^{st} – 12^{th}) and last twelve (37^{th} – 48^{th}) hours of study, respectively. Considering the first twelve hours, the viscosity of the fresh green tomato juice (GRTJ) reduced from 2.25 to 2.09 cP indicating a 7.66% reduction. Furthermore, the viscosity of the GRTJ decreased on an hourly basis for the first five (1^{st} – 5^{th}) hours and the values were significantly different ($\alpha_{0.05}$), indicating a reduction in the quality of the juice with time. However, at a stretch of the 7^{th} to the 12^{th} hour of study, the viscosities of the GRTJ were not significantly different indicating no variation in its quality. Thus, the viscosity of the GRTJ decreased with time and reached its peak at the seventh hour.

After the first hour, the viscosity of the yellowish–orange tomato juice (YORTJ) decreased from 1.49 to 1.38 cP (7.97% reduction). The viscosity of the juice at the 2^{nd} and 3^{rd} hour was significantly lower ($\alpha_{0.05}$) than the viscosity at the 1^{st} hour, indicating a reduction in quality. The viscosity on the 3^{rd}, 4^{th} and 5^{th} hour of the study was not significantly different ($\alpha_{0.05}$) indicating the same quality, but was significantly lower than viscosity on the 1^{st} and 2^{nd} hour, indicating a further reduction in quality. However, at a stretch of the 8^{th} to 10^{th} hour of study, the viscosities of the YORTJ were not significantly different ($\alpha_{0.05}$) with no further reduction in viscosity, indicating no variation in its quality. Therefore, the viscosity of the YORTJ also decreased with time and reached its peak at the eighth hour.

On the other hand, after the 1^{st} hour, the viscosity of the red tomato juice (RRTJ) reduced from 1.39 to 1.35 cP (2.96% reduction); the viscosities reduced from the 1^{st} to the 8^{th} hour and the values were significantly different at $\alpha_{0.05}$ indicating reduction in quality. Furthermore, the viscosity of the RRTJ at the 9^{th} and the 10^{th} hour was not significantly different but was significantly lower than the 1^{st} to the 7^{th} hour indicating further reduction in its quality. However, no further reduction in viscosity was observed from the 9^{th} to 10^{th} hour indicating the 9^{th} hour as the peak of viscosity reduction. Longer time (9^{th} hour) before the viscosity of RRTJ is reduced to its minimum level suggests a longer period before the loss of its quality. Perhaps, it has undergone stability during the process of transition from green to yellowish–orange and finally to red ripening stage.

Comparison of viscosity of green, yellowish–orange and red ripening staged of tomato juices showed that viscosity of the GRTJ was significantly higher ($\alpha_{0.05}$) than the viscosity of each of YORTJ and RRTU, indicating higher quality of GRTJ over YORTU and RRTJ. The viscosity of the YORTJ was significantly higher than RRTJ at all times except on the 1^{st} hour, indicating higher quality of the YORTJ over RRTJ. Thus, for the period of the 2^{nd} to 12^{th} hour, the viscosity of the RRTJ was significantly lower than the viscosity of YORTJ while that of YORTJ was lower than the GRTJ.

In the last twelve (37^{th} - 48^{th}) hours, it was observed that the viscosity of GRTJ was not significantly different starting from the 39^{th} hour and remained so throughout, indicating no change in viscosity. On the other hand, the viscosity of the YORTJ was not significantly different starting from the 37^{th} hour and remained so till the the 48^{th} hour with values ranging from 1.20 to 1.23 cP, indicating that the viscosity remained the same. However, the viscosity of the RRTJ exhibited fluctuation; the values were not significantly different at 37^{th}, 39^{th}, 40^{th}, 41^{st}, 45^{th} and 46^{th} hour with the viscosity of 1.09 cP and not significantly different at 42^{nd}, 43^{rd}, 44^{th}, 47^{th} and 48^{th} hour with viscosity that is higher than 1.09 cP.

Comparison of the viscosity of the juices at different ripening stages showed that at the 37^{th} to the 47^{th} hour, the viscosities of the GRTJ and YORTJ were not significantly different ($\alpha_{0.05}$) indicating that they have degraded to the same extent. On the other hand, from the 37^{th} to the 48^{th} hour, the viscosity of the RRTJ was significantly lower than the viscosity of each of GRTJ and YORTJ, which indicated that it has undergone higher degradation (loss of quality) than the GRTJ and YORTJ. The levels of reduction observed in viscosities of the fresh tomatoes monitored for the first 12 hours were 26.22 % (2.25 – 1.66 cP, GRTJ),

18.79% (1.49 – 1.21 cP, YORTJ) and 16.55% (1.39 – 1.16 cP, RRTJ). Thus, the % of reduction in viscosities followed an order η RRTJ < η YORTJ < η RTJ; the quality followed the reverse order. However, the levels of overall reduction observed in viscosities of the fresh tomatoes monitored for 48 h were 44.89% (2.25 – 1.24 cP, GRTJ), 19.46% (1.49 – 1.20 cP, YORTJ) and 19.42% (1.39 – 1.12 cP, RRTJ). The % of reduction in viscosities of the YORTJ and RRTJ are approximately the same and were lower than the level in GRTJ. This implied that YORTJ and RRTJ have better quality retention than GRTJ, and are better stages for consumption of tomatoes.

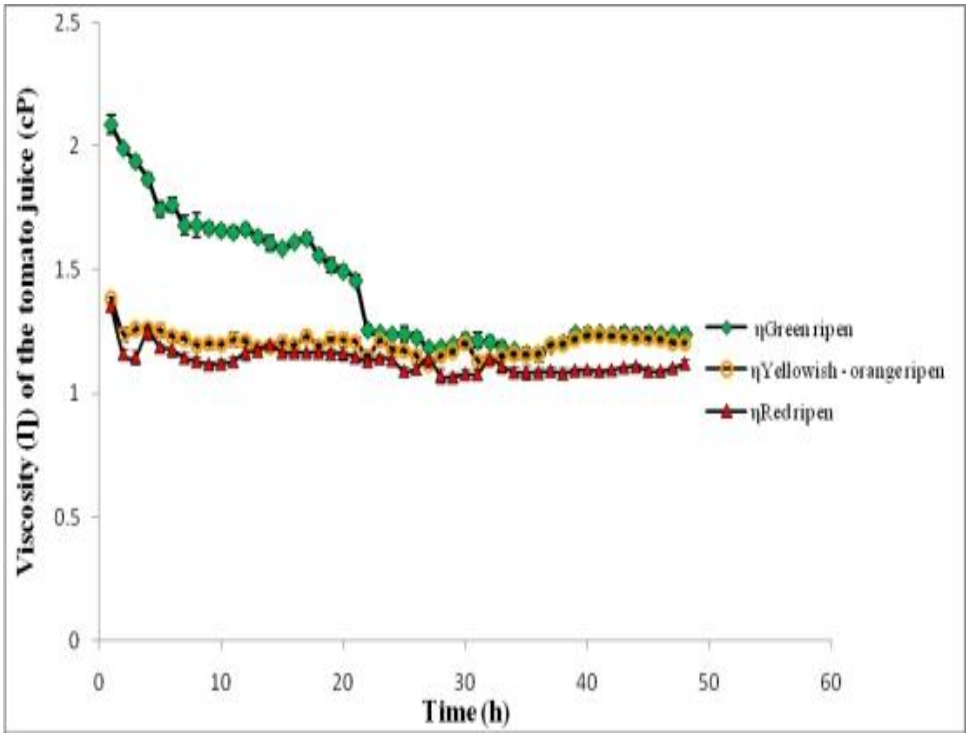

Fig. 2. Time dependence of viscosity of tomato juices at three different ripening stages

Table 1. Viscosity of tomato juices at three different ripening stages monitored for the first twelve hours (1st to 12th)

Time (hour)	Viscosity (cP) at different ripening stages		
	green ripening	yellowish–orange Ripening	red ripening
0	2.25 ± 0.02	1.49 ± 0.01	1.39 ± 0.02
1	2.09 ± 0.04$^{f(b)}$	1.38 ± 0.01$^{e(a)}$	1.35 ± 0.01$^{f(a)}$
2	1.99 ± 0.00$^{e(c)}$	1.32 ± 0.02$^{d(b)}$	1.25 ± 0.03$^{e(a)}$
3	1.94 ± 0.02$^{d(c)}$	1.26 ± 0.02$^{c(b)}$	1.15 ± 0.03$^{abc(a)}$
4	1.87 ± 0.02$^{c(c)}$	1.26 ± 0.02$^{c(b)}$	1.16 ± 0.02$^{bcd(a)}$
5	1.75 ± 0.03$^{b(c)}$	1.26 ± 0.03$^{c(b)}$	1.19 ± 0.01$^{d(a)}$
6	1.76 ± 0.03$^{b(c)}$	1.23 ± 0.02$^{abc(b)}$	1.18 ± 0.03$^{cd(a)}$
7	1.68 ± 0.04$^{a(c)}$	1.24 ± 0.03$^{bc(b)}$	1.15 ± 0.02$^{abc(a)}$
8	1.68 ± 0.05$^{a(c)}$	1.20 ± 0.02$^{a(b)}$	1.13 ± 0.02$^{ab(a)}$
9	1.67 ± 0.02$^{a(c)}$	1.20 ± 0.02$^{a(b)}$	1.12 ± 0.01$^{a(a)}$
10	1.66 ± 0.02$^{a(c)}$	1.20 ± 0.02$^{a(b)}$	1.12 ± 0.02$^{a(a)}$
11	1.65 ± 0.02$^{a(c)}$	1.22 ± 0.03$^{ab(b)}$	1.13 ± 0.02$^{ab(a)}$
12	1.66 ± 0.02$^{a(c)}$	1.21 ± 0.02$^{ab(b)}$	1.16 ± 0.03$^{bcd(a)}$

The results are presented as means ± SD for triplicate analysis

$^{(a-f)}$Means followed by different letters on the same column are significantly different at $\alpha_{0.05}$

$^{(a-c)}$Means followed by different letters on the same row are significantly different at $\alpha_{0.05}$

Table 2. Viscosity of tomato juices at three different ripening stages monitored for the last twelve hours (37^{th} to 48^{th})

Time (hour)	Viscosity (cP) at different ripening stages		
	green ripening	yellowish–orange Ripening	red ripening
37	$1.20 \pm 0.02^{a(b)}$	$1.20 \pm 0.02^{a(b)}$	$1.09 \pm 0.03^{ab(a)}$
38	$1.20 \pm 0.01^{ab(b)}$	$1.20 \pm 0.02^{a(b)}$	$1.08 \pm 0.02^{a(a)}$
39	$1.24 \pm 0.02^{bc(c)}$	$1.22 \pm 0.01^{a(b)}$	$1.09 \pm 0.01^{ab(a)}$
40	$1.24 \pm 0.01^{bc(b)}$	$1.23 \pm 0.02^{a(b)}$	$1.09 \pm 0.01^{ab(a)}$
41	$1.25 \pm 0.02^{bc(b)}$	$1.23 \pm 0.01^{a(b)}$	$1.09 \pm 0.01^{ab(a)}$
42	$1.24 \pm 0.02^{bc(b)}$	$1.23 \pm 0.02^{a(b)}$	$1.10 \pm 0.01^{b(a)}$
43	$1.25 \pm 0.01^{bc(b)}$	$1.23 \pm 0.02^{a(b)}$	$1.10 \pm 0.01^{b(a)}$
44	$1.24 \pm 0.02^{bc(b)}$	$1.23 \pm 0.02^{a(b)}$	$1.10 \pm 0.01^{b(a)}$
45	$1.24 \pm 0.02^{bc(b)}$	$1.22 \pm 0.02^{a(b)}$	$1.09 \pm 0.02^{ab(a)}$
46	$1.24 \pm 0.02^{bc(b)}$	$1.22 \pm 0.01^{a(b)}$	$1.09 \pm 0.01^{ab(a)}$
47	$1.24 \pm 0.03^{bc(b)}$	$1.21 \pm 0.01^{a(b)}$	$1.10 \pm 0.01^{b(a)}$
48	$1.24 \pm 0.02^{bc(c)}$	$1.20 \pm 0.02^{a(b)}$	$1.12 \pm 0.02^{b(a)}$

The results are presented as means ± SD for triplicate analysis
$^{(a-c)}$Means followed by different letters on the same column are significantly different at $\alpha_{0.05}$
$^{(a-c)}$Means followed by different letters on the same row are significantly different at $\alpha_{0.05}$

The results of the viscosity established in this study and the quality parameters adopted from the report of Rahman et al. (2019) for fresh tomatoes are shown in Table 3 and the results of their correlation are presented in Table 4. The correlation coefficients showed good ability in establishing pH (0.96) and chlorophyll (0.91). Thus, it is easier to identify the suitable ripening stage by looking at the colour of the tomatoes displayed for sale in the market.

Table 3. Viscosity and quality parameters of fresh tomatoes from this study and report of Rahman et al. (2019) respectively

Ripen stages	[a]Viscosity [[a]I] (cP)]	[b]Firmness	[b]Lightness	[b]Hue angle	[b]Chlorophyll (µg/g)	[b]Ascorbic acid (mg/100g)	[b]Total Soluble Solid (%)	[b]Titratable Acidity (%)	[b]pH
GR	2.25	88	60.2	117.7	11.2	18.7	4.11	0.51	4.43
YOR	1.49	85	55.1	108.5	5.7	19.9	4.32	0.52	4.11
RR	1.39	52.2	38.5	53.7	0	13.7	4.02	0.64	3.9

GR: green ripening; YOR: yellow-orange ripening; RR: red ripening
[a]I]: This study; b: Rahman et al. (2019)

Table 4. Correlation of viscosity and quality parameters of fresh tomatoes from this study and report of Rahman et al. (2019) respectively

	Viscosity	Firmness	Lightness	Hue angle	Chlorophyll	Ascorbic acid	Total Soluble Solid	Titratable Acidity	pH
Viscosity	1								
Firmness	0.67	1							
Lightness	0.76	1	1						
Hue angle	0.70	1	1	1					
Chlorophyll	0.92	0.92	0.96	0.93	1				
Ascorbic acid	0.44	0.96	0.92	0.95	0.77	1			
Total Soluble Solid	-0.13	0.66	0.56	0.63	0.31	0.84	1		
Titratable Acidity	-0.65	-1	-0.99	-1	-0.91	-0.97	-0.68	1	
pH	0.96	0.86	0.92	0.87	1	0.68	0.18	0.84	1

Conclusions

The quality of tomatoes at three different ripening stages has been established using an Ubbelohde viscometer; the viscosities of fresh tomatoes differed from one ripening stage to the other and reduced with time, indicating depreciation of quality. However, the tomato of the fresh green ripening stage with the highest viscosity degraded rapidly indicating poor quality retention in comparison with yellowish–orange and red ones which underwent gradual degradation. It is, therefore, more nutritionally suitable to consume tomatoes of yellowish–orange and red ripening stages which can easily be identified.

Author Contributions: Dr. M. A. Fakunle: Experimental design, viscometer construction and manuscript preparation. Dr. W. B. Agbaje: Experimental design and supervision as well as manuscript preparation. Mr. E. A. Aninku: Laboratory work for data generation

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