Innovative Systems Design and Engineering
ISSN 2222-1727 (Paper) ISSN 2222-2871 (Online)
Vol.6, No.2, 2015

Kinetic Modeling of Mango Fruit Ripening

C.I.O. Kamalu[1] and I. J. Okolie[1,2*]
1.Department of Chemical Engineering, Federal University of Technology, P.M.B. 1526, Owerri, Nigeria.
2. Department of Chemical Engineering, University of Lagos, Lagos, Nigeria
*E-mail of correspondent author: connect_isioma@yahoo.com

ABSTRACT

In this work, three stages of mango ripening (mango ripening, ethylene inducement, rotting) are modelled kinetically. Data for mango ripening are obtained from internet, and are used to perform regression analysis of the kinetic models developed. It is seen that the results show linear relationship between concentrations and conversion for all the chemical components in all the models (fig. 1a, 2a, 3a). Also the results of the concentration-time relationship are highly non-linear (fig. 1b, 2b and 3b). The reciprocal of the reaction rates varies non-linearly with conversion: profile of ethylene inducement and rotting rise exponentially while that of mango ripening falls non-linearly. The result of this study will help those dealing with fruits in orchard during harvesting and post harvest handling.
Keywords: mango fruit ripening, ethylene, kinetic modelling, maturing, rotting, stoichiometry

1.0 INTRODUCTION

1.1 Background of the Study

The phenomenon of the kinetics of fruit ripening in general and mango ripening in particular has been a controversially confusing study due to inadequate records, observations, experiments and now modelling of some of its natural behavioural mechanism with mathematics.

As mango ripening is an irreversible chemical reaction between the chemical constituents (nutrients) of the mango, there is lack of mathematical model to predicatively determine the concentration of any of the components of a ripped/ripening mango at any time. Hence, the exact nutritional value of a ripped or ripening mango is not known with time unless a correct mathematical model expressing the relationship of concentration of the components of a ripening mango with time is established.

Fruit dealers have problems of handling and storage of fruits. Mango fruit being a tropical fruit is usually harvested matured-green and is then transported or shipped for marketing [Cocozz *et a*l., 2014; Baker, 1997, Bansal, 2000]. Fruit dealers are faced with the problem of exact period fruits must not overstay during the storage period or on the tree. Nutritionist also are faced with the problem of predicting the exact nutritional value of a mango fruit at any given time, since the compositions of a mango are dynamic as the mango ripens. Also problems of variation of chemical components in the mango with time or with other chemicals also exist. This is because there is no predictive model for some of these fruits. If for instance a dealer knows exactly how much time a ripped fruit should stay before it goes rotting, it will make him harvest and sell the fruit on time. Again if he knows the time lag for some chemicals to depart from the fruit or react with other chemicals to give a bad taste, it will help him sell the fruit on time.

The significant of the study is to generate mathematical models that will be capable of predicatively determine the compositional change of mango fruit with time as it ripens and rottens and the relationship between the chemical components of mango fruit as it ripens.

The objective of this study is to model a predictive relationship between the varying nutrients (chemical compounds) with time or with other chemical compounds so as to know when the fruit would stay and still be edible or sour (beginning to rotting) so that the fruit dealers can be fully equipped with this knowledge.

The study does not include the influence of the diffusion of material across the mango flesh (succulent) parts on ripening. It does not include the effect of temperature on mango ripening as data used in the modelling were data from experiments at constant temperature (20^{o}C) and it does not include the formation of ethylene and starch and the action of enzymes.

Table 1: Comparison of Fruit Ripening With Vegetable and Animal Nutrition (Prescott, 1878)

In Vegetable Nutrition	In Plant Ripening	In Animal Nutrition
Oxygen is given out	Oxygen is taken from the air	Oxygen is taken from the air
Carbonic acid is taken from the air	Carbonic acid is given out to the air	Carbonic acid is given out to the air
The service of plant green is required	The service of plant green is dismissed	
Simple compounds are changed to those more complex	Complex compound are changed to those more simple	Complex compounds are changed to those more simple
The expended power of the sun is stored	The store-up power of the sun is expended	The store-up power of the sun is expended
Heat is absorbed	Heat is liberated	Heat is librated

2.0 Prescott's Mango Ripening

The sugar of fruits is chiefly formed or deposited in them during their ripening. It has been pretty generally held that starch in the unripe fruits is converted into sugar in the ripe fruits; fruits acids inducing the change (Prescott, 1878, Burdon et al., 1996). Comparison of fruit ripening, vegetable and animal nutrition has been presented Table 1.

It has been advanced that sugar is formed from malic acid and other acids, during ripening, either in the fruit or the parts of the plant supplying juice to the fruit (Prescott, 1878, FAO, 1983, 1993, 1999). According to Prescott, "six molecules of malic acid, and six molecules of tartaric acid, with nine molecules (eighteen atoms) of oxygen, would furnish the atoms for formation of four molecules of glucose, twelve molecules of water and twenty four molecules of carbonic anhydride". The quantities of both acid and sugar increase in the fruit so long as it is still green and emitting oxygen in the daylight, the branches which bore the fruit containing acid and peptones substances but no sugar (Prescott, 1878, Mahayothee et al., 2004, Ito et al., 1997).

The increase of weight of fruits, during ripening, is no doubt largely owing to deposition of sugar. Bernard found that 100 parts of unripe summer peaches yielded 179 parts of ripe fruit and 100 parts of unripe apricots increased in ripening to 200 parts (Prescott, 1878, Muda et al., 1995, Ketsa et al., 1999).

The maturity of fruit is the period of its maximum quantity of sugar. Sooner or later, the quantity of sugar begins to diminish and then the fruit is overripe. It is safe to say that sugar begins to decompose during the time of over-ripping to rottening. The five classes of Fruit products include: sugars (starches), pectous substance and gums, acids, tannin and other glucosides, esters and lastly alkaloids (USOA / ARS, 2007
, Wills et al., 2001). In general terms, sugar suffers oxidation in ripe fruits; small portions being oxidized away even during the production of large portions and before perfect maturity.

The final products of oxidation, carbonic acids and water are exhaled during ripening and with greater rapidity after maturity has been passed (Reddy and Srjvaslava, 1999, Jha et al., 2007).

2.1 Acid Profiles

The quantity of acids in the fruits usually diminishes during ripening. The diminution is not however early so great as it appears to tastes, because the acid of ripe fruits is marked to the taste by the larger proportions of sugars and the pectous substances then present. The removal of acids is chiefly due to oxidation. It is not found that acids are neutralized to any considerable extent during ripening, by alkalis conveyed through the stem. Sugar has no chemical effect upon acids. Its very sweet taste masks or overpowers the sense the sour taste pf free acid; but the acids remain free, all the same (Yahia, 1998, Yahia et al., 2006a).

3.0 DEVELOPMENT OF MODELS

Mango fruit ripening process is divided into three stages: ripening stage; ethylene inducement stage and after maturation-rotting stage. All the three stages of mango ripening are chemical reactions hence kinetic models of unknown orders and constants are developed for the 3 stages, and, least square techniques were used to regress and calculate the unknown constants i.e. rate order and rate constants, and then, placed into the developed models.

The model ODE is then solved so that there will be no unknown constants left in the models. The dependent and independent variables of the models are now plotted using nonparametric fit called interpolant (shape preserving) since there is no remaining unknown parameter (constant) to measure.

Model 1: (mango ripening):

According to Prescott (Prescott, 1878), the word equation for mango ripening is

6 malic acid + 6 tartaric acid + 9 oxygen → 4 glucose + 12 water + 24 carbonic anhydride.

Symbolically:

$$aA + bB + cC \xrightarrow{k} dD + eE + fF \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1a)$$

$$\frac{r_A}{-a} = \frac{r_B}{-b} = \frac{r_C}{-c} = \frac{r_D}{d} = \frac{r_E}{e} = \frac{r_F}{f} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1b)$$

$$A + \frac{b}{a}B + \frac{c}{a}C \rightarrow \frac{d}{a}D + \frac{e}{a}E + \frac{f}{a}F \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1c)$$

$$\frac{r_A}{-6} = \frac{r_B}{-6} = \frac{r_C}{-9} = \frac{r_D}{4} = \frac{r_E}{12} = \frac{r_F}{24} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1d)$$

Table 2a: Stoichiometric table for the reaction

Species	Symbols	Initially	Change	Remaining	Concentration	Concentration
Malic acid	A	N_{AO}	$-N_{AO}X$	$N_{AO}(1-X)$	$C_{AO}(1-X)$	$C_{AO}(1-X)$
Tartaric acid	B	N_{BO}	$-N_{BO}X$	$N_{AO}(\Theta_B-X)$	$C_{AO}(\Theta_B - X)$	$C_{AO}(1-X)$
Oxygen	C	N_{CO}	$-\frac{3}{2}N_{AO}X$	$N_{AO}(\Theta_C-\frac{3}{2}X)$	$C_{AO}(\Theta_C-\frac{3}{2}X)$	$\frac{3}{2}C_{AO}(1-X)$
Glucose	D	N_{DO}	$\frac{3}{2}N_{AO}X)$	$N_{AO}(\Theta_D+\frac{3}{2}X)$	$C_{AO}(\Theta_D-\frac{3}{2}X)$	$\frac{3}{2}C_{AO}X$
Water	E	N_{EO}	$2N_{AO}X$	$N_{AO}(\Theta_E+2X)$	$N_{AO}(\Theta_E+2X)$	$2C_{AO}X$
Carbonic anhydride	F	N_{FO}	$4N_{AO}X$	$N_{AO}(\Theta_F+4X)$	$C_{AO}(\Theta_F+4X)$	$4C_{AO}X$
Inert	I	N_{IO}	-	N_{IO}	C_{IO}	C_{IO}

where $\Theta_B = \frac{N_{BO}}{N_{AO}} = \frac{6}{6} = 1$; $\Theta_C = \frac{N_{CO}}{N_{AO}} = \frac{9}{6} = \frac{3}{2}$;

$\Theta_D = \Theta_E = \Theta_F = \frac{N_{DO}}{N_{AO}} = \frac{N_{EO}}{N_{AO}} = \frac{N_{FO}}{N_{AO}} = \frac{0}{6} = 0$;

This is because before ripening commences, the products concentrations were all zero.

Let the rate of conversion of malic acid = $-r_A = \frac{d_{CA}}{dt} = KC_A^aC_B^bC_C^c$

Where K = reaction rate constant; a, b, and c are the orders wrt A, B and C. Taking log of both sides.

$\Rightarrow In(-r_A) = Ink + a.InC_A + b.InC_B + c.InC_c$

This is equivalent to $Y = a_o + ax_1 + bx_2 + cx_3$ …………………………… (2)

Using least square method, we obtain the normal equations.

$\Sigma Y - na_o - a\Sigma x_1 - b\Sigma x_2 - c\Sigma x_3 = 0$ …………………………….. (3a)

$\Sigma yx_1 - ao\Sigma x_1 - a\Sigma x_1^2 - b\Sigma x_1x_2 - c\Sigma x_1x_3 = 0$ …………………………… (3b)

$\Sigma yx_2 - ao\Sigma x_2 - a\Sigma x_1x_2 - b\Sigma x_2^2 - c\Sigma x_2x_3 = 0$ …………………………… (3c)

$\Sigma yx_3 - a_o\Sigma x_3 - a\Sigma x_1x_3 - b\Sigma x_2x_3 - c\Sigma x_3^2 = 0$ …………………………… (3d)

which yield the following on application of data (Prescott, 1878, Mahayothee et al., 2004, USOA / ARS, 2007

Table 2b: Regression table

s/n	t(hrs)	C_A	C_B	C_C	$r_A = \frac{d}{}$	y-Inr$_A$	X1=InC$_A$	X2=InC$_B$	X_3=InC$_C$	YX_1	x_1^2	X_1X_2	X_1X_3	YX_2	X_2^2	X_2X_3	YX_3	X_3^2
1.	0	21	39.38	12.6	0.617	-0.483	3.045	3.673	2.534	-1.471	9.272	11.184	7.716	1.774	13.4971	9.307	-1.224	6.421
2.	6	19.48	36.53	11.69	0.283	-12.62	2.969	3.598	2.459	-3747	8.815	10.082	7.301	-4.541	12.946	8.848	-3.103	0.225
3.	12	17.6	33.0	10.56	0.290	-1.238	2.868	3.497	2.357	-3.551	8.225	10.029	6.760	-4.329	12.229	8.242	-3.253	5.556
4.	18	16.0	30.0	9.60	267	-1.321	2.773	3.401	2.262	-3.663	7.690	9.140	5.979	-4.493	11.567	7.693	-2.988	5.227
5.	24	14.40	27.0	8.64	0.189	-1.666	2.667	3.296	2.156	-4.443	7.113	8.790	5.750	-5491	10.864	7.106	-3.592	4.648
6.	36	12.6	23.63	7.56	0.150	-1.897	2.534	3.163	2.023	-4.807	6.421	8.015	5.126	-6.00	10.005	6.399	-3.838	4.093
7.	48	10.80	20.25	6.48	0.100	-2.303	2.380	3.008	1.819	-5.481	5.664	7.159	4.329	-6.927	9.048	3.472	-4.189	3.309
8.	72	9.0	16.88	5.40	0.079	-2.197	2.826	1.686	-5.576	4.827	6.209	3.704	7.172	7.986	4.765	-4.279	2.843	4.765
Σ	216	120.88	22.667	72.53	1975	-12.708	21.433	28.462	17.296	-32.739	58.027	71.208	46.665	-40.727	88.136	57.832	-26.466	38.212

$\Sigma y = -12.708$
$\Sigma x_1 = 21.433$, $\Sigma x_2 = 28.462$
$\Sigma x_3 = 17.296$, $\Sigma yx_1 = -32.739$, $\Sigma x_2^2 = 38.027$, $\Sigma x_1x_2 = 71.208$, $\Sigma x_1x_3 = 4.665$
$\Sigma yx_2 = -40.727$, $\Sigma yx_2^2 = 88.136$, $\Sigma x_2x_3 = 57.832$, $\Sigma yx_3 = -26.466$, $\Sigma x_3^2 = 38.212$
$a_o = -0.1694$, $a = 0.1945$, $b = -0.2795$, $c = 0.044$

$$\Rightarrow k = e^{ao} = e^{-0.1694} = 0.8442$$

Also

$$\alpha = a + b + c = 0.1945 - 0.2795 + 0.044 = -0.4294$$

From rate equation

$$-r_A = \frac{dc_A}{dt} = KC_A^a C_B^b C_C^c \quad \text{...} \quad (4)$$

$$C_{AO}\frac{d(1-x_A)}{dt} = k[C_{Ao}(1-x_{AO})]^a\,[C_{Ao}(1-x_A)]^b\left[\left(\frac{3}{2}\right)C_{AO}(1-x_A)\right]c \text{........} \quad (5)$$

$$C_{AO}\frac{d(1-x_A)}{dt} = KC_{AO}{}^{a+b+c}(3/2)^c.(1-x_A)^{a+b+\mathbf{c}} \quad \text{..................................} \quad (6)$$

$$\frac{dx_A}{dt} = KC_{AO}{}^{a-1}(3/2)^c.(1-x_A)^\alpha \quad \text{. ....} \quad (7)$$

$$= -\frac{d(1-x_A)}{dt} = KC_{AO}{}^{a-1}(3/2)^c.(1-x_A)^\alpha$$

Separating variables

$$= -\frac{dX_A}{(1-X_A)^\alpha} = KC_{AO}{}^{\alpha-1}(3/2)^c dt$$

$$-\int_{XA}^{0}(1-X_A)^{-\alpha}\,dX_A = KC_{AO}^{\;a-1}(3/2)^c\int_t^0 dt$$

$$\left[1-(1-X_A)^{1-\alpha}\right]=KC_{AO}^{\;a-1}(3/2)^c\,(1-\alpha)dt$$

$$\Rightarrow\; X_A = 1-[1-KC_{AO}^{\;a-1}(3/2)^c\,(1-\alpha)t]^{\wedge}\left(\tfrac{1}{1-\alpha}\right) \quad \ldots\ldots (8)$$

Substituting the values of the constants, we have

$$X_A=\left\{1-\left[1-\frac{1.2287t}{C_{AO}^{\;1.4294}}\right]\right\}^{0.6996}$$

For the acids (malic and tartaric acids)

$$MTC_{ON}=C_{AO}(1-X_A)=C_{AO}\left[1-\frac{1.2287t}{C_{AO}^{\;1.4294}}\right]0.6996 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9a)$$

For oxygen

$$O_2conc=\frac{3}{2C_{AO}(1-X_A)}=\frac{3}{2C_{AO}\left[\frac{1.2287t}{C_{AO}^{\;1.4294}}\right]^{0.6996}} \quad \ldots\ldots\ldots\ldots\ldots.. \quad (9b)$$

For glucose formation

$$G_{conc}=\frac{2}{3}C_{AO}X_A=\frac{2}{3}C_{AO}\left[1-\left[1-\frac{1.2287t}{C_{AO}^{\;1.4294}}\right]^{0.6996}\right] \quad \ldots\ldots\ldots\ldots\ldots.. \quad (9c)$$

For water formation

$$G_{conc}=2C_{AO}\left[1-\left[1-\frac{1.2287t}{C_{AO}^{\;1.4294}}\right]^{0.6996}\right] \quad \ldots\ldots\ldots\ldots\ldots.. \quad (9d)$$

For carbonic anhydride formation

$$Carbonic_{Con}=4C_{AO}X_A=4C_{AO}\left[1-\left[1-\frac{1.2287t}{C_{AO}^{\;1.4294}}\right]^{0.6996}\right] \quad \ldots\ldots\ldots\ldots\ldots.. \quad (9e)$$

Model 2: Ethylene Inducement

From literature (Prescott, 1878) it is said that ethylene reacts with malic acid to break down into sugar. This statement is captured as ethylene + malic acid $\longrightarrow$ sugar .. (10a)

$CH_2 = CH_2 + HOOCCH_2CHOHCOOH + H_2O \longrightarrow C_6H_{12}O_6$ .... (10b)

Table 3a: Stoichiometric table

Species	Symbol	Initially	Change	Remaining	Concentration	Concentration
ethylene	A	N_{AO}	$-N_{AO}X$	$N_{AO}(1\text{-}X)$	$C_{AO}(1\text{-}X)$	$C_{AO}(1\text{-}X)$
malic acid	B	N_{BO}	$-N_{AO}X$	$N^{AO}(\theta_B^{-}X)$	$C_{AO}(\theta_B^{-}X)$	$C_{AO}(1\text{-}X)$
water	C	N_{CO}	$-N_{AO}X$	$N_{AO}(\theta_c\text{-}X)$	$C_{AO}(\theta_C^{-}X)$	$C_{AO}(1\text{-}X)$
sugar	D	N_{DO}	$N_{AO}X$	$N_{AO}(\theta_D + X)$	$C_{AO}(\theta_D^{-}X)$	$C_{AO}X$
Inert	I	N_{IO}	-------	N_{IO}	C_{IO}	C_{IO}

$$\theta_B = \frac{N_{BO}}{N_{AO}} = \frac{1}{1} = 1,\ \theta_C = \frac{N_{CO}}{N_{AO}} = \frac{1}{1} = 1, \theta_D = \frac{N_{DO}}{N_{AO}} = \frac{0}{1} = 0$$

Similarly, taking log of both sides rate equation, using least square technique to obtain normal equations and solving for rate equation constants we have

$$\sum y - na_o - \alpha\sum X_1 - \beta\sum X_2 - r\sum X_3 = 0 \quad \ldots\ldots\ldots \quad (11a)$$

$$\sum yX_1 - a_o\sum X_1 - \alpha\sum X_1^2 - \beta\sum X_1X_2 - r\sum X_1X_3 = 0 \quad \ldots\ldots\ldots \quad (11b)$$

$$\sum yX_2 - a_o\sum X_2 - \alpha\sum X_1X_2 - \beta\sum X_2^2 - r\sum X_2X_3 = 0 \quad \ldots\ldots\ldots \quad (11c)$$

$$\sum yX_3 - a_o\sum X_3 - \alpha\sum X_1X_3 - \beta\sum X_2X_3 - r\sum X_3^2 = 0 \quad \ldots\ldots\ldots \quad (11d)$$

$a_o = -3.1244$, $\alpha = 1.7672$, $\beta = -0.9642$, $\gamma = 0.8468$

$k = e^{ao} = e^{-3.1244} = 0.04396$, $\theta = \alpha + \beta + \gamma = 1.6498$

Solving the rate equation for this model 2 yields

$X_A = 1 - [1 - C_{AO}^{\theta} - 1K(1-\theta)t]\ 1/1 - \theta$ ………………………….. (12)

And substituting the values of the constants gives

$X_A = 1 - [1 + 0.02856C_{AO}0.6498t]^{-1.5389}$ ………………….. (13)

For ethylene, acid and H_20

EAWconc

$= C_{AO}(1 - X_A) = C_{AO}[1 + 0.02856C_{AO}0.6498t]^{-1.5389}$ ………………… (14a)

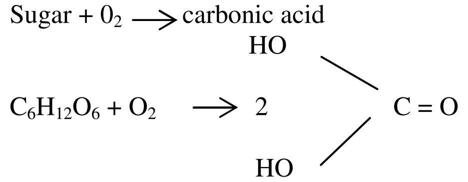
For sugar

Sconc $= C_{AO}X_A = C_{AO}\ \ 1\text{-}[1\{+ 0.02856C_{AO}0.6498t]^{-1.5389}$ ……….. } (14b)

Model 3: After Maturity (rotting)

After maturity i.e. during rotting, oxygen reacts with sugar to produce carbonic acid.

Sugar + 0_2 → carbonic acid



$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ H_2CO_3$

Table 4a: Stoichiometric table for the reaction

Species	Symbol	Initially	Change	Remaining	Concentration	Concentration
Sugar	A	N_{AO}	$-N_{AO}X$	$N_{AO}(1\text{-}X)$	$C_{AO}(1\text{-}X)$	$C_{AO}(1\text{-}X)$
O_2	B	N_{BO}	$-6_{NAO}X$	$N_{AO}(\Theta B - 6x)$	$C_{AO}(\Theta_B^{-}6x)$	$6C_{AO}(1\text{-}X)$
Carbonic	C	N_{CO}	$6_{NAO}X$	$_{NAO}(\theta_c + 6x)$	$C_{AO}(\theta_C + 6x)$	$6C_{AO}X$
Inert	I	N_{IO}	-------	N_{IO}	C_{IO}	C_{IO}

NOTE: $\theta_B = \frac{N_{BO}}{N_{AO}} = \frac{6}{1} = 6, \theta_c = \frac{N_{CO}}{N_{AO}} = \frac{0}{1} = 0$

Again, going through the entire rituals yields

$$\sum Y - na_o - \alpha\sum X_1 - \beta\sum X_2 = 0 \quad \ldots\ldots\ldots \quad (15a)$$

$$\sum YX_1 - a_o\sum X_1 - \alpha\sum X_1^2 - \beta\sum X_1X_2 = 0 \quad \ldots\ldots\ldots \quad (15b)$$

$$\sum YX_2 - a_o \sum X_2 - \alpha \sum X_1 X_2 - \beta \sum X_2^2 = 0 \quad \ldots\ldots\ldots\ldots\ldots \quad (15c)$$

a_o = 0.0166, α = - 0.1682, β = 0.8487

$k = e^{ao} = e^{0.0166} = 1.01692$

$\gamma = \alpha + \beta = 0.6805$

$X_A = 1 - [1 - 6\beta C_{AO}^{\gamma-1} K(1-\alpha)t]^{1/(1-r)}$ ………………………………. (16)

Substituting the values of the constants

$$X_A = 1 - \left[1 - \frac{1.4625t}{C_{AO}0.3195}\right]^{3.1299} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

For sugar

$$\text{Su conc} = C_{AO}(1 - X_A) = C_{AO}\left[1 - \frac{1.4625t}{C_{AO}0.3195}\right]^{3.1299} \quad \ldots\ldots\ldots\ldots \quad (18a)$$

For oxygen

$$O_2 = 6C_{AO}(1 - X_A) = 6C_{AO}\left[1 - \frac{1.4625t}{C_{AO}0.3195}\right]^{3.1299} \quad \ldots\ldots\ldots\ldots \quad (18b)$$

For carbonic acid

$$\text{Carbonic conc} = 6C_{AO}X_A = 6C_{AO}\left(1 - \left[1 - \frac{1.4625t}{C_{AO}0.3195}\right]^{3.1299}\right) \ldots\ldots\ldots\ldots \quad (18c)$$

3.1 Relationship Between Inverse Rate and Conversion

For model:

$$\frac{1}{-rA} = \frac{1}{KC_{AO}^{\alpha}(1 - X_A)^{\alpha}} = 4.3784(1 - X_A)^{0.4294} \quad \ldots\ldots\ldots\ldots \quad (19a)$$

For model 2:

$$\frac{1}{-rA} = \frac{1}{KC_{AO}(1 - X_A)^{\theta}} = \frac{1}{5.0276(1 - X_A)^{1.6498}} \quad \ldots\ldots\ldots\ldots \quad (19b)$$

For model 3:

$$\frac{1}{-rA} = \frac{1}{K6^{\beta}C_{AO}^{\alpha-1}(1 - X_A)^{\alpha}} = \frac{1}{2.1377(1 - X_A)^{0.6805}} \quad \ldots\ldots\ldots\ldots \quad (19c)$$

4.0 RESULTS

The solution to all the models were obtained graphically using matlab software 7.9 as and the results:

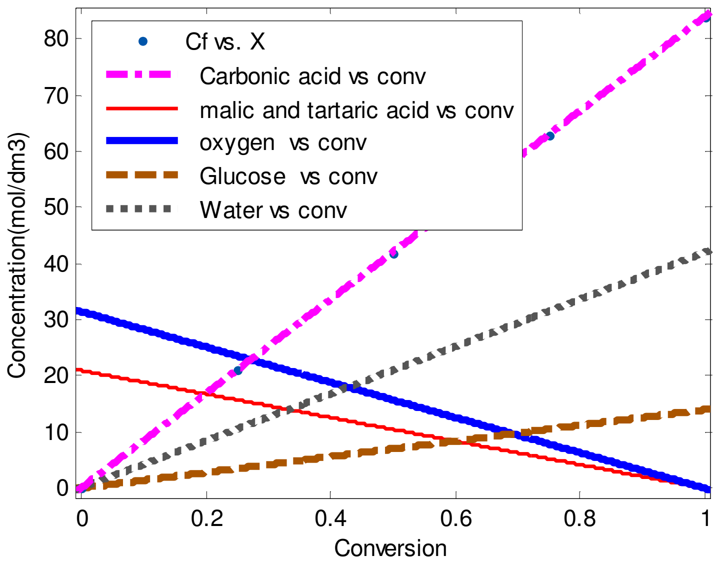


Fig.1a;Concentration as a function of conversion(mango fruit ripening)

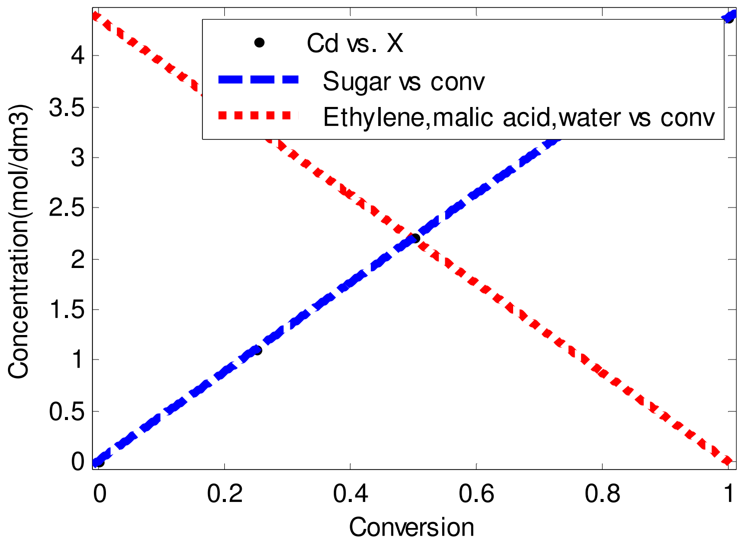


Fig2a;Concetration as a function of conversion(mango fruit, natural ethylene inducement

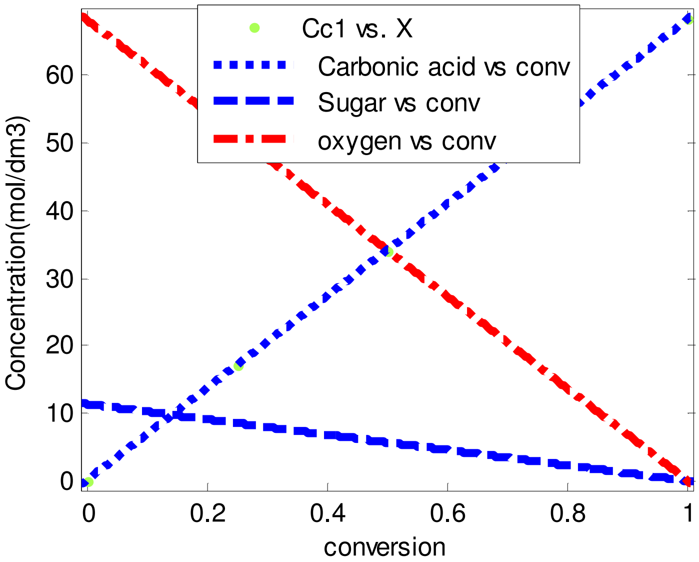


Fig3a;Concentration as a function of conversion
(mano fruit rottening)

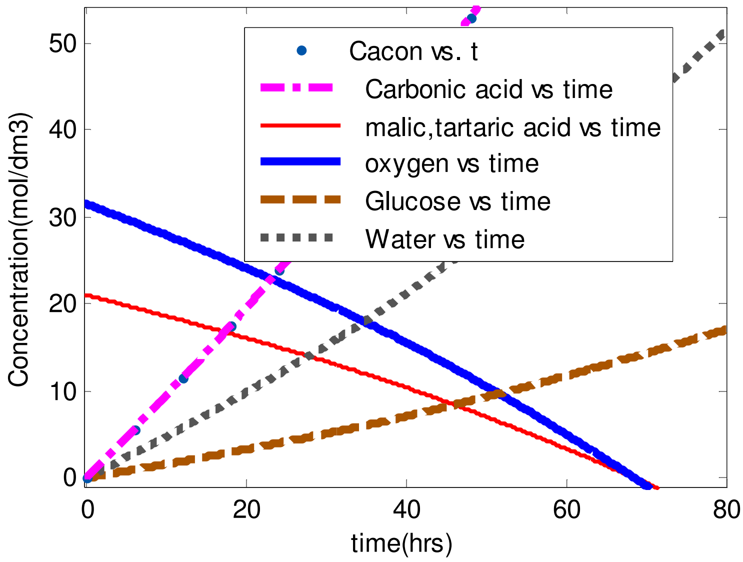


Fig1b;Concentration versus time(model 1,fruit ripening)

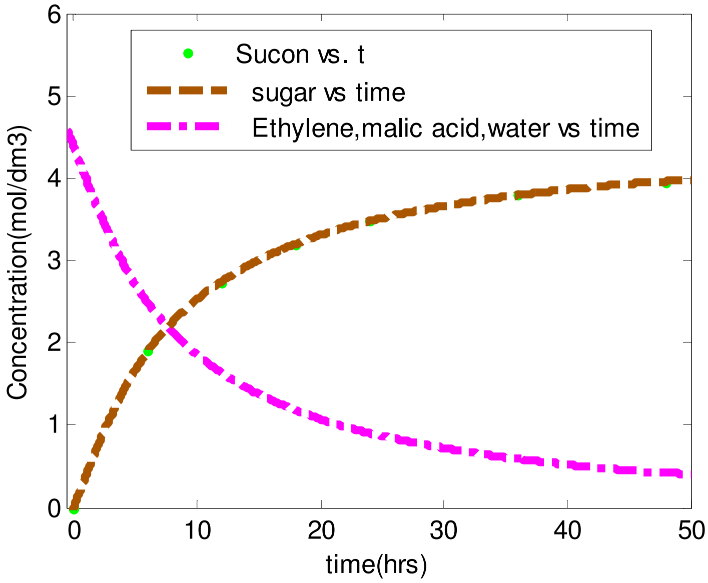


Fig2b;Concentration versus time(model 2,natural ethylene inducement)

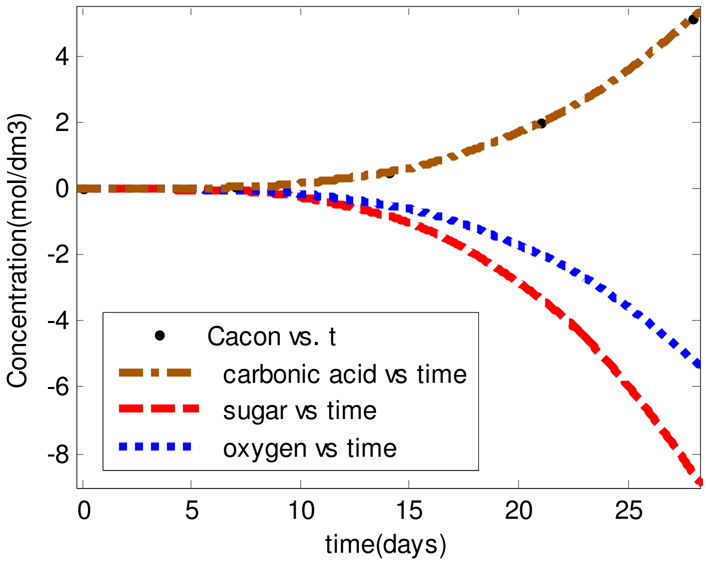


Fig3b;Concentration versus time(model 3,fruit rottening)

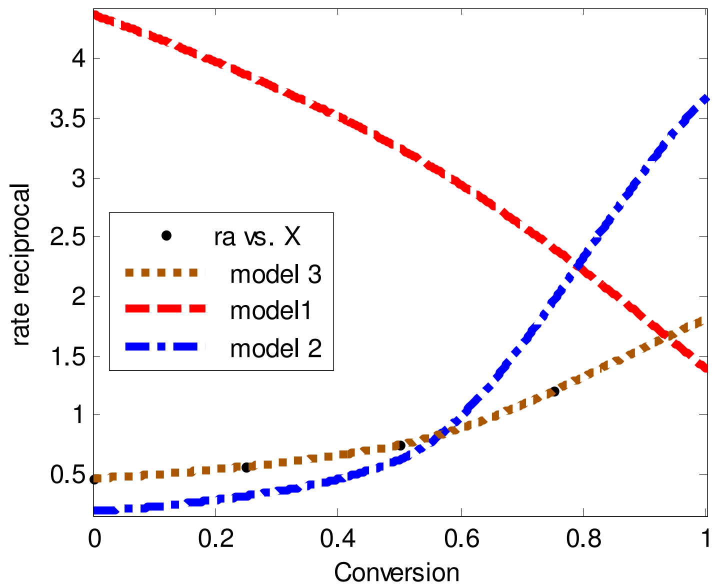


Fig 4 ;Rate reciprocal versus conversion for models 1,2 and3)

5.0 DISCUSSION

5.1 Concentration versus Conversion

In fruits ripening (model 1) it is seen that while concentrations of malic and tartaric acids and, oxygen decrease (linearly) in the fruit that of glucose, water and carbonic acid increase with conversion to give the ripening mango a good taste (fig. 1a).
In ethylene inducement (Model 2): ethylene which reacts with malic acid and water begins to decrease as sugar increases impacting the fruit with its characteristic sweet taste (fig. 2a), but in rotting stage (Model 3) concentration of sugar and oxygen begin to leave while carbonic anhydride with its bad taste increases (fig. 3a).

5.2 Concentration - time

In mango ripening (Model 1). The concentration of oxygen, tartaric acid and malic acid begin to decrease as concentration of carbonic acid, water and glucose increase, non-linearly with increase in time (fig. 1b). This tallies with Prof. Prescotts' statement in ethylene inducement (Model 2), concentration of ethylene, malic acid and water decrease in a negative exponential with time while that of sugar increase positively exponentially (fig. 2b). In rotting concentration of sugar and oxygen go negative while that of carbonic acid with bad taste increases with time, all of course, non-linearly (fig. 3b).
In figure 4, the reaction rate reciprocal of model two and three rises with conversion in almost exponential form while that of model 1 behaves in a reverse form i.e. falling non-linearly with increase in % conversion.
These variations can also be traced from the tables (2a – 4a) used in plotting the graph.

6.0 CONCLUSION

In this work, three stages of mango ripening (mango ripening, ethylene inducement, rotting) are modelled kinetically. Data for mango ripening are obtained from internet, and are used to perform regression analysis of the kinetic models developed. It is seen that the results show linear relationship between concentrations and conversion for all the chemical components in all the models (fig. 1a, 2a, 3a). Also the results of the concentration – time relationship are highly non-linear (fig. 1b, 2b and 3b).
The reciprocal of the reaction rates varies non-linearly with conversion: profiles of ethylene inducement and rotting rise exponentially while that of mango ripening falls non-linearly. The result of this study will help those dealing with fruits in orchards during harvesting and post harvest handling.

REFERENCES

Baker, R.A. (1997). 'Reassessment of some fruit and vegetable pectin levels. J. Food Sci. 225 – 229.

Bansal, K.C. (2000). Biotechnology for Improving Product Quality in Horticultural and Plantation Crops', Malhotra Publishing House, New Delhi, India. pp 201 – 218.

Burdon, I., Dori, S., Marinansky, R. and Pesis, E. (1996). Acetaldehyde Inhibition of ethylene in Biosynthesis in Mango Ripening, post harvest Biology and Technology, pp 5, 153 – 161.

Cocozza, F.M., Jorge, J.T., Alves, R.E., Filgueiras, H.E. and Pereira, M.E. (2004). Sensory and Physical Evaluation of Cold Stored Mangoes. Acta horticulture, pp 645- 661.

FAO, Production Year Book (1983, 1993, 1999). Food and Agricultural Organization of the United Nations, Rome, Italy.

Ito, T., Sasaki, K. and Yoshida, Y. (1997) Changes in respiration rate, saccharide and organic acid content during the development and ripening of mango fruit (Mangifera indica L. 'Irwin') cultured in a plastic house. Journal of the Japanese Society for Horticultural Science. 66, 629–635.

Jha, S.N., Chopra, S. and A.R.P Kingsly, A. R. P., 2007. Modeling of colour values for non destructive evaluation of maturity of mango. Food Engineering 78: 22-26.

Ketsa, S., Phakawatmangko, I.W. and Subhadrabhanhu, S. (1999). Peel Enzymatic Activity and Colour Changes in Ripening Fruit. Journal of Plant Physiology 154, 363 – 366.

Mahayothee, S. Mahlbaeur, W., Neidhart, S. and Caries, R. (2004). Influence of Post harvest Ripening Process on Appropriate maturity for Drying Mangoes 'Nam Dokmai' and 'Kaew' Acta Horticulture 645, 241 – 248.

Muda, P., Seymour, C.B., Errington, N. and Teuker, C.A. (1995). Compositional Changes in Cell Wall Polymers During Mango fruit Ripening. Carbohydrate Polymers 26, 225 – 260.

Prescott, A.B. (1878). The Chemistry of fruit-ripening, Popular Science monthly Vol. 12: February 1878.

Reddy, V.Y. and Srjvaslava, G.C. (1999). Ethylene Biosynthesis and Respiration in Mango Fruits during Ripening. Journal of Plant Physiology 4, 59 – 70.

United States Oeparlmenl of Agriculture (Usoa)/Agriculture Research Services (Ars) (2007) Usoa National Nutrient Oatabasc for Standard Reference, Release 20. Nutrient Data Labaratary Home Page. Available Al:http://www.arts.Usda.Gov/Nutriendata (Accessed 28 August 2008).

Wills, R. & H, Warton, M.A., Mussa, D.M. and Chew, L.P. (2001). Ripening of Mango Fruits at low Ethylene Levels. Journal of Experimental Agriculture 41, 89 – 92.

Yahia, E. (1998). 'Modified and controlled atmospheres for tropical fruits. Hort. Rev. 22: 123 – 183.

Yahia, E.M. Omeles-Paz, I. Dej. and Ariza F.R. (2006a). The Mango, Editorial Trillas Mexico City, Mexico, 224 pp (In Spanish).