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KINETICS OF THERMAL SOFTENING OF AFRICAN YAM BEAN (*Sphenostylis stenocarpa*) SEEDS AS INFLUENCED BY HEATING MEDIUM TRONA CONCENTRATIONS DURING CONVENTIONAL COOKING

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Abstract

Sensory evaluation and instrumental tester were used to determine softness and hardness of cooked AYB seeds. A 9-point Hedonic scale was used for sensory evaluation, while hardness of the seeds was measured in kgf/m^3. Cooking temperatures of 80, 85, 90 and 95^{o}C were adopted using distilled water with 0, 0.5, 1.0 and 1.5 % trona concentration over 90 minutes interval. Panelist results of mean sensory score on a scale of 9 to 1 for thermal softening of the seed all obeyed zero order kinetic, while puncture force for hardness followed a first order kinetic model. Thermal firmness decreased from 9.3692 to 0.1253 min^{-1} as temperature and trona concentration increased, while the softening rate constant increased from 0.1227 to 0.2120 min^{-1} under the same condition. The D-values, cook-values, Z-values, order of process and Q_{10} all showed temperature dependence of the softening rate constant. Therefore, cooking of AYB seeds in trona concentration reduced the cooking time by a factor of 1.5 to 2.0. The Puncture force (F) equivalent on a descriptive scale (X) of 3 described as well-cooked in the various trona concentrations of 0, 0.5, 1.0 and 1.5% trona concentration were calculated as 1.243, 1.113, 1.0245 and 0.2785 N/m^2, respectively. The principal component analysis of the sensory score and puncture force measurement for thermal softening as influenced by thermal concentration showed a positive correlation (r^2 0.996). This implies that the developed equations in this study are essential for predictive purposes during cooking of AYB.

Keywords: Kinetics, African yam beans, Thermal softening, Trona, Conventional, cooking.

1.0 Introduction

Dry African yam beans (*Sphenostylis stenocarpa*) are one of the most important lesser-known legume grains for human consumption. The dry African yam bean (AYB) is widely recognized in the traditional diets of many regions in West Africa including

Nigeria. AYB are excellent sources of protein (25-30%), carbohydrate (50-69 %) and good sources of fiber, minerals and vitamins (Aremo *et al.,* 2019). They constitute diets of most developing countries, but less significant in Western diets. In spite of the high nutritional value, the seeds contain high amount of antinutrients such as trypsin inhibitors, phytates, oxalates, saponins and haemagglutinins (Gbenga-Fabusiwa, 2021) and exhibit hard-to-cook phenomenon requiring longer cooking times during food preparations.

Numerous pre-processing and processing methods have been employed in the preparation of AYB diets, possibly to reduce these antinutrients and render the seeds palatable including. Soaking of AYB seeds before cooking as the most common practice used in softening the seeds and hastening the cooking process (Tura *et al.,* 2025). Thermal processing treatments of foods in general cause significant quality degradation, especially, heat-labile constituents of foods and organoleptic factors (Sruthy *et al.,* 2022). These changes are important to processors and consumers because they are the major determinants of quality and acceptability of foods (Ling *et al.,* 2015). However, in traditional processing, common alkaline salt such as trona has been added in the cooking water to accelerate hydration of the beans considered necessary to reduce cooking time and increase tenderization of the seed texture (Chigwedere, 2018). As cooking proceeds, trona treated water penetrates the seed coat to increase softness of the cotyledon and ultimately to produce well-cooked seeds with acceptable texture as one of the most critical attributes sensory quality control (Nwosu *et al.*, 2010).

Kinetic studies of food deterioration have been made possible to gain insight in the understanding of the mechanisms controlling rates of reaction during processes such as physical, chemical, biochemical and microbiological reactions that can lead to quality loss (Ling *et al.,* 2015). This will allow a wider scope of investigation for the more efficient process under different conditions to optimize quality. Hence, knowledge of the effect of trona concentration on cooking time, temperature is necessary for optimization of sensory and nutritional quality retention in terms of the obtained kinetic parameters and derivatives. Many studies have used instrumental measurements in texture analysis of extruded snack products to complement the sensory evaluation, but such information on legume seeds is scanty.

2.0 Objectives of the study

The broad objective was to study the kinetics of thermal softening of AYB as influenced by trona concentration during cooking using subjective and objective methods and correlations with sensory analysis based on puncture force and sensory scores for the texture of AYB.

3.0 Materials and Methods

3.1 Materials

The legume seeds of dark brown local cultivar of African yam beans (AYB) (known as *Ahuma in Tiv)* used for the study were purchased from Ortese Market, Mkar, Gboko Local Government Area of Benue State, Nigeria. The seeds were transported to the Food Science and Technology laboratory of Joseph Sarwuan Tarka University, Markurdi. The AYB seeds were manually sorted and cleaned to remove broken, small sized, split seeds, dust and other extraneous materials. The whole seeds were then stored in air tight plastic containers and kept at room temperature of 30±5^{o}C before subsequent processing.

3.2 Methods

3.3 Subjective measurements.

Sensory evaluation of cooked AYB seeds was carried out using descriptive measurements by a panel of 12 member trained judges, using 1 structural sensory scale to evaluate the texture for degree of softening. The panelists training consisted of preliminary assessment of ability of 20 members to discriminate between extremely hard and extremely soft perceptions of AYB and ability to determine when the seeds are well-cooked. The sensory evaluation of the degree of softness was then carried out by the 12 selected members who evaluated the AYB seeds cooked in the 0, 0.5, 1.0 and 1.5% trona solutions, at 10min intervals over 90 min cooking time at each of 80, 85, 90, 95 and 100 ^{o}C, respectively. Became of boiling point depression, 100 ^{0}C cooking was achieved using a pressure cooker.

At each heating interval, samples were rapidly cooled in ice-bath to 35^{o}+2 ^{o}C prior to serving to the panelists. The test samples were presented in transparent plates with 3-digits coded random numbers. Transparent spoons were presented with the

samples. Each plate contained 30 seeds and the judges were requested to judge the doneness of the seeds on a hardness descriptive scale of extremely hard (9), very hard (8), hard (7), slightly hard (6), slightly soft (5), soft (4), very soft/well cooked (3), extremely soft (2) and putty/mushy (1). Sensory evaluation was carried out in a special sensory laboratory with partitioned boots between 11:00am – 12:00 noon on each evaluation day. Order of presentation of the samples was completely randomized in terms of judges and test products. The sensory mean scores for each test sample were subjected to reaction kinetic evaluations.

2.4 Objective measurements

Objective measurements for thermal softening of the AYB seeds were carried out using a modification of the puncture force method described by Bourne (1989) and Anzaldua Morales *et al*. (1996). Puncture force of 40 seeds for each cooking temperature (80 °C – 100 °C) and trona heating medium concentrations of (0, 0.5, 1.0, and 1.5%) at interval of 10 min. were measured using a VMT Monsanto hardness Tester Machine (Liverpool England). With a 2mm diameter cylindrical punch with a pointed end. The test seeds were placed on the surface of a flat table after 10 minutes interval and the pointed end of the tester placed on the seed with application of the desired force to penetrate the seed. The reading of the tester was measured as hardness of the seed in kgf/m^3, or kilograms force per cube meters. Force for complete puncture of the seed versus time was obtained and plotted by means of computer excel program. At 80 and 85 °C, the puncture force varied only slightly (about 1% of original value), hence, puncture force data at 90, 95 and 100 °C, respectively, were used for kinetics of objective thermal softening determinations.

3.5 Kinetic data Analysis

Textural evaluation of the thermal softening kinetics of AYB seeds at constant temperatures were calculated as described by Villota and Hawkes (2018) and Ismail *et al*. (1996) as follows:

The general rate law was applied using equation (1)

$$dc/dt = +kC^n \quad (1)$$

Where C = value of sensory quality attribute at time t (min), k = reaction rate constant (min), n = reaction order

Reaction rate constants were calculated graphically using linearized equation (1);

$C_0 - C - kt$ (2)

For zero order reactions,

$\ln C_0/C = kt$ (3)

For first order reactions, where C_0 = initial value of mean sensory textural score.

The best fit order based on coefficient of regression (r^2) and linearity of the curves were used for subsequent evaluations.

For 90 % reduction in initial value, t = D at a given temperature. The D – values become:

For zero order reaction

$$\text{Log}10 = \frac{k}{2.303} D \quad (4)$$

Therefore, $D = 2.303/k$ (5)

In the decimal reduction time approach, D-values (min) were related to temperature, T (°C) as follows:

$$\ln D_T = \ln D_0 - \frac{1}{2}(T - T_0) \quad (6)$$

Where D_T = decimal reduction time at temperature T(°C), D_0 = decimal reduction time at T=0°C (representing the intercept coefficient of decimal reduction curve) and z (°C) as the reciprocal slope index representing the change in temperature (°C) for the decimal reduction curve to pass through one log cycle.

3.6 Puncture force evaluation

Curves of puncture force (kgf) versus cooking times for the AYB seeds were analyzed using the equation described by Bourne (1989) and also Anzaldua – Morales *et al*., (1996) as follows:

$\text{Log } F = \text{Log } Fi - kt$ (7)

For a pseudo-first order kinetics of softening of vegetable tissues, where F = puncture force at time (t) Fi = puncture force at initial or zero cooking time (taken as intercept coefficient of the semi-log plot and regarded as "thermal firmness" in this study), k_s = apparent rate constant for softening.

The temperature dependence of the kinetic data was verified using the Arrhenius activated complex model shown below:

$K = k_o \exp. (- Ea/RT)$ (8)

Where k_o = frequency or collision factor (independent of temperature), Ea = activation energy (ks/mol), R = universal gas constant (0.008314 KT/mol. deg), T = absolute temperature (^oK)

Linearization of Eq. (8) gave

$$\text{Log } k = \text{Log } K_0 - \frac{Ea}{2.303R} \frac{1}{T} \quad (9)$$

For puncture force,

$$Ks = N \exp. (- Ea/RT) \quad (10)$$

And

$$\text{Log } Ks = \text{Log } N' - \frac{Ea}{2.303R} . \frac{1}{T} \quad (11)$$

Where N' = constant, T = absolute temperature (^0K).

The temperature dependence of reactions in biological systems is also expressed in terms of Q_{10} – value defined as the change in reaction rate constant accompanying a 10^0C change in temperature (Toledo, 1981) as follows:

$$\frac{K2}{K} = (Q10)^{T_2 - T_1/10} \quad (12)$$

K_1 = reaction rate constant corresponding to temperature T_1 (^0C), K_2 = reaction rate constant corresponding to temperature T_2 (^0C).

3.7 Determination of Correlations

The principal component relationship between puncture force and sensory scores for texture is given as follows:

Plot of InF versus X (13)

Where X = value of sensory scores corresponding to texture

F = puncture force in kF/m^3

Then the correlation relationship between puncture force and sensory score for texture is

given by:

$LogF=A+Bx$

(14)

Where F = puncture force, kF/m^3,

S = sensory scores for texture

A= intercept

B = Slope

X = mean sensory texture scores

3.8 Statistical Analysis

Linear regression analysis was employed for interpretation of kinetic data using computer software and principal components analysis to generate regression coefficients (r^2).

4.0 Results and Discussion

4.1 Subjective texture Measurement.

The sensory mean scores for subjective thermal softening of AYB seeds during cooking in 0 – 1.5% trona at 80 – 100^0C were subjected to evaluation by zero and first order reaction kinetics equation (2) and (3). Based on the linearity and higher r^2 values, the zero order kinetics was used to describe the subjective thermal softening of the AYB seeds. The first order kinetics did not hold any advantage. On a descriptive scalar values with 9= extremely hard, 3 = very soft/well-cooked and 1 = mushy/putty, the zero order plots expressed as percentages (with score of 9 = 100% hard) are shown in figure 19 for heating in distilled water or 0 % trona (Plot A), 0.5% trona (Plot B), 1.0% trona (Plot C) and 1.5% trona (Plot D), respectively, the curves were linear with lower values as trona concentrations increased.

The regression parameters for cooking in 0, 0.5, 1.0 and 1.5% trona are provided in Table 1. The thermal firmness and thermal softening rate constants ranged from 9.9148 at 80 °C to 9.1611 at 100 °C and 0.1033 min^{-1} at 80 °C to 0.1253 min^{-1} at 100 °C, respectively, for cooking in 0 % trona

. For cooking in 0.5 % trona, the thermal firmness ranged from 9.9088 (80 °C) to 8.1500 (100 °C) with thermal softening rate constants that varied from 0.1116 to 0.1320 min^{-1} within 80 – 100 °C.

Thermal firmness varied from 9.3692 to 8.5081 while thermal softening rate constant ranged from 0.1089 to 0.1624 min^{-1} within 80 °C – 100 °C cooking in 1% trona for the 1.5% trona cooking medium, the thermal firmness ranged from 8.8742 to 8.6200 while thermal softening rate constant varied from 0.1227 to 0.2120 min^{-1} showing increase in rates as temperature increased from 80 to 100 °C.

The curves for the changes in hardness profile of AYB seeds during cooking at (80, 85, 90, 95 and 100 °C) respectively as influenced by heating medium 0%, 0.5%, 1.0% and 1.5% trona concentration was best described by a zero-order based on linearity and higher r^3 than for first order kinetics relationship.

The rate constant increased with increase in temperature and trona concentrations. Cooking times (cook-value) for doneness of the AYB seeds were significantly ($P<0.5$) decreased by use of trona in the heating medium. As expected, increase in cooking temperature resulted in decreased cooking times at all trona concentrations. It must be pointed out that The subjective kinetic data were based on responses from human senses and perceptions of firmness. These perceptions are prone to human bias even though a trained panel of judges was employed for the sensory evaluation. Hence, the kinetic data analysis should be taken with caution. However, for a zero order reaction kinetics, the appropriate cooking times (on a descriptive scale with 9 as extremely firm and 3 as very soft/well-cooked AYB seeds were evaluated. The use of trona at 0.5, 1.5 and 1.5% percent in cooking medium reduced the cooking time of the DBS of AYB cultivars by factors of about 1.5 to 2 during cooking at 80 to 100 °C

The heated seeds increased in size due to swelling. This could be attributed to rapid water absorption and starch gelatinization (Bourne, 1989; Anzaldua-Morales *et al.,* 1996). The seeds boiled in trona solutions had higher swelling and cracks which increased with trona concentrations. Starch gelatinization and swelling of the seeds in addition to protein denaturation could explain the textural charges resulting in exposure of more actives sites for heat penetration and thermal softening.

The temperature dependence of the subjective thermal softening of the DBS of the AYB cultivar could be explained in terms of z-values, D-values, cook values, order of process and Q_{10} values. The D-value is regarded as time at a given cooking temperature for 90% reduction in firmness. Z-value represents the temperature changed of the decimal reduction curve to pass though one log cycle. D-values and z-values are

measures of thermal resistance to softening of the seeds.

The Z-values of the AYB during cooking at 0%, 0.5%, 1.0% range from 38.3 to 57.6 °C. The Z-value indicates the sensitivity of a component response to temperature change. Low z-value or high D-value are important to understand the usefulness of the influence of temperature, on the other hand, high value of Z or low D-value indicates that temperature is of secondary importance (Comet *et al*., 1999). The Z-values for texture are at an intermediary range and very much similar while the Z-values of most heat resistance enzymes and vitamins are significantly higher. At trona concentration above 0.5%, the panelists were able to detect flavor of trona and drawiness on the tongue; hence, 0.5% trona heating medium is recommended for thermal softening of the AYB seeds.

The subjective derived parameters for the zero – order kinetics are also shown in Table 1. The D-values reduced with increase in cooking temperature and trona concentrations. The D-values varied from 78 to 64.6min, 72.6 to 61.4min, 74 to 50.8 min and 66 to 35.3 min for 0, 0.5, 1.0 and 1.5% trona concentrations, respectively.

Cook values (adequate process time) ranged from 58 to 47.9 min (0% trona), 53.0 to 45.5 min (0.5% trona), 50 to37 min (1.0% trona) and 48.9 to 28.3 min (1.5% trona). This indicates that the use of trona in the heating medium reduced the cooking time of AYB seeds by factors of about 1.1 to 1.3, and 1.7 during cooking with 0.5, 1.0 and 1.5% trona, respectively.

The z-values decreased with increase in trona concentration and ranged from 39 to 16.9^{0}C for thermal softening of AYB seeds. The temperature quotient for the subjective measurement of thermal softening of AYB seeds was 1.5 at all trona concentrations

4.2 Objective measurements of puncture Force.

Plots of puncture force against cooking time as provided in figure 20. While Table 24 shows result of regression parameters for semi-Log plot of In F versus X for the effect of 0% trona concentration in the heating medium on the puncture force of AYB seeds during cooking at different temperatures (90, 95 and 100^{0}C).

At 0% trona concentration, puncture force at 90, 95 and 100 ^{0}C were as follows:

$\text{Log } F_{90} = 0.675 + 0.0954(x)$: Coefficient of regression $(r^2) = 0.924$ (15)

$\text{Log } F_{95} = 0.2639 + 0.2319(x)$: Coefficient of regression $(r^2) = 0.945$ (16)

$\text{Log } F_{100} = 0.3865 + 0.1298(x)$: Coefficient of regression $(r^2) = 0.936$ (17)

Mean Log F = 0.4419 + 0.1524 (x) with mean coefficient of regression (r^2) = 0.935 (18)

Table 2 shows results of regression parameters for Semi-Log plots of In F versus X for the effect of 0.5% trona concentration in the heating medium on the puncture free of AYB seed during cooking at different temperature (90, 95 and 100 ^{0}C)At 0.5% trona concentration it puncture force at 90, 95 and 100 ^{0}C were:

Log F_{90} = 0.7523 + 0.0859(x) coefficient of regression (r2) = 0.944 (19)

Log F_{95} = 0.7063 + 0.0944(x) coefficient of regression (r2) = 0.978 (20)

Log F_{100} = 0.6148 + 0.1047(x) coefficient of regression (r2) = 0.957 (21)

∴ Mean Log F = 0.6911 + 0.0950 (x) mean coefficient of regression (r^2) = 0.960 (22)

Table 2 shows results of regression parameter for Semi-Log Plot of In F versus X for the effect of 1.0% trona concentration of the healing medium in the puncture force of AYB seeds during cooking of different temperature (90, 95 and 100 ^{0}C).

At 1.0% trona concentration the puncture force at 90, 95 and 100 ^{0}C were:

Log F_{90} = 0.8107 + 0.0841(x) coefficient of regression (r2) = 0.892 (23)

Log F_{95} = 0.5165 + 0.1101(x) coefficient of regression (r2) = 0.974 (24)

Log F_{100} = 0.5609 + 0.1019(x) coefficient of regression (r2) = 0.954 (25)

∴ Mean Log F = 0.6314 + 0.0987 (x) mean coefficient of regression (r2) = 0.904 (26)

Table 2 show results of regression parameter for semi-Log plot of In F versus X for the fleet of 1.5% trona concentration of the heating medium on the puncture force of AYB seeds during cooking at different temperature 90, 95 and 100 ^{0}C.

At 1.5% trona concentration puncture at 90, 95 and 100 ^{0}C were:

Log F_{90} = 0.5945 + 0.1009(x) coefficient of regression (r2) = 0.934 (27)

Log F_{95} = 0.4223 + 0.1067(x) coefficient of regression (r2) = 0.969 (28)

Log F_{100} = 0.4547 + 0.1050(x) coefficient of regression (r2) = 0.984 (29)

∴ Mean Log F = 0.4922 + 0.1042 (x) mean coefficient of regression (r2) = 0.962 (30)

Comparing equation 1 to 4 (r2) values for the regression coefficient of 0.962 at 1.5% trona concentration were the highest while mean regression coefficient of 0.904 was the least.

The firmness or hardness of the AYB sees where measured instrumentally using a penetrometer which measured the force needed to puncture the seeds. The puncture force at different cooking times in 0, 0.5, 1.0 and 1.5% trona heating medium respectively were each measured at 80, 85, 90, 95 and 100^{0}C. Data obtained wee adequately described by pseudo-first order reaction kinetics in agreement with reports by Bourne (1989) and Anzaldua-Morales *et al*. (1996). However, the puncture force versus time curves for all trona heating medium concentrations were linear unlike the broken cooking curves reported by Bourne (1989) for softening of biological tissues and Anzaldua-Morales *et al*., (1996) for six legumes during cooking the authors studied pinto beans, white beans, black beans, chick peas and lentils. There legumes unlike the study on AYB seeds were pre-soaked for about 11hr prior to cooking in distilled water. In this present study, the AYB seeds were not pre-soaked and were heated in different trona solutions. This could explain the variations in the heating curves. The puncture force decreased with increase in cooking time, temperature and trona concentration of heating medium.

Equations developed in this study (Eq. 36 to 52) are useful for estimation of the puncture force needed for process design and optimization when the AYB seeds are cooked in different trona solutions. The puncture force can be related to subjective firmness scales for prediction purposes via correlation relationship.

4.3 Correlation between subjective and Objective Measurements

Fig shows the principal component relationship between puncture force and mean sensory scores for conventional cooking of AYB at 90, 95 and 100^{0}C respectively as influenced by trona concentrations (0%, 0.5%, 1.0%, 1.5%) in the heating medium.

The equation that best describe the principal component relationship between puncture force and mean sensory scores for texture of AYB seeds during conventional cooking at 90, 95 and 100^{0}C in 0% trona concentration (Plot A), 0.5% trona concentration (Plot B), 1.0% trona concentration (Plot C), and 1.5% trona concentration (D) were given as

follows:

Mean Log F = 0.4419+0.1524 (X) r^2 = 0.935 at 0% trona concentration (55)

Mean Log F = 0.6911+0.0950 (X) r^2 = 0.960 at 0.5% trona concentration (56)

Mean Log F = 0.6314+0.0987 (X) r^2 = 0.940 at 1.0% trona concentration (57)

Mean Log F = 0.4922+0.1642 (X) r^2 = 0.961 at 1.5 trona concentration (58)

Respectively.

Therefore, using Y=A+BX (59)

Hence the average is obtained as follows:

F=A+BX plotted in the principal component relationship for correlations (60)

Where B= slope, A=intercept,

X= mean sensory scores for texture when the seeds are well cooked

Results of descriptive analysis of firmness of the AYB seeds were correlated with the instrumental objective measurements using Pearson correlation of the principal component (sensory scores and puncture force). A high positive correlation ($r^2 > 0.96$) was established between the sensory scores (used as independent variable) and the objective instrumental puncture force measurements (as dependent variable). Previous worker by Harada *et al.* (1985) noted positive correlations between subjective and objective methods. Galina *et al*. (2015) also reported that a positive correlation between sensory and instrumental analysis snap beans. According to Szczesniak (1983), correlation between and instrumental measurements are needed in (1) finding instruments to measure quality control of foods in industries; (2) predicting consumers response as the degree of liking and the overall acceptance of a new product; (3) understanding what is being sensed and perceived in the mouth during sensory assessment of texture; (4) improving or optimizing their instrumental methods to complement the sensory evaluation.

Puncture force tests (Paula and conti-silva, 2014; Ding *et al*; 2006; Pamies *et al*, 2000 and Nascrimento *et al*., 2012) have been used to measure firmness or hardness of food materials. Most of these works including a study by Anzaldua-morales *et al*. (1996) on the kinetics of thermal softening of six legumes during cooking were only on instrumental analysis without correlation with subjective measurements. In the evaluation of firmness or hardness of AYB seeds during conventional cooking, the correlation between subjective data and objective puncture force test data. The

correlation ship between instrumental and subjective measurements developed in this present study (Equations 29 to 44) are therefore essential for predictive purposes. These models for firmness or hardness (defined as force for the molar teeth to compress the AYB seeds) will enable application of the instrumental puncture force tests as an indication of the sensory texture of cooked AYB seeds. Therefore, using the mean correlation equation for 0%, 0.5%, 1.0% and 1.5% trona concentration of the heating medium, the puncture force (F) equivalent to the descriptive scale (X) of 3 (very well-cooked) for the AYB seeds were calculated to b 1.243, 1.1125, 1.0245 and 0.2785 N/m^2, respectively. This implies that these equations can be applied to predict the equivalent puncture force for any given numerical value of texture and trona concentration during cooking.

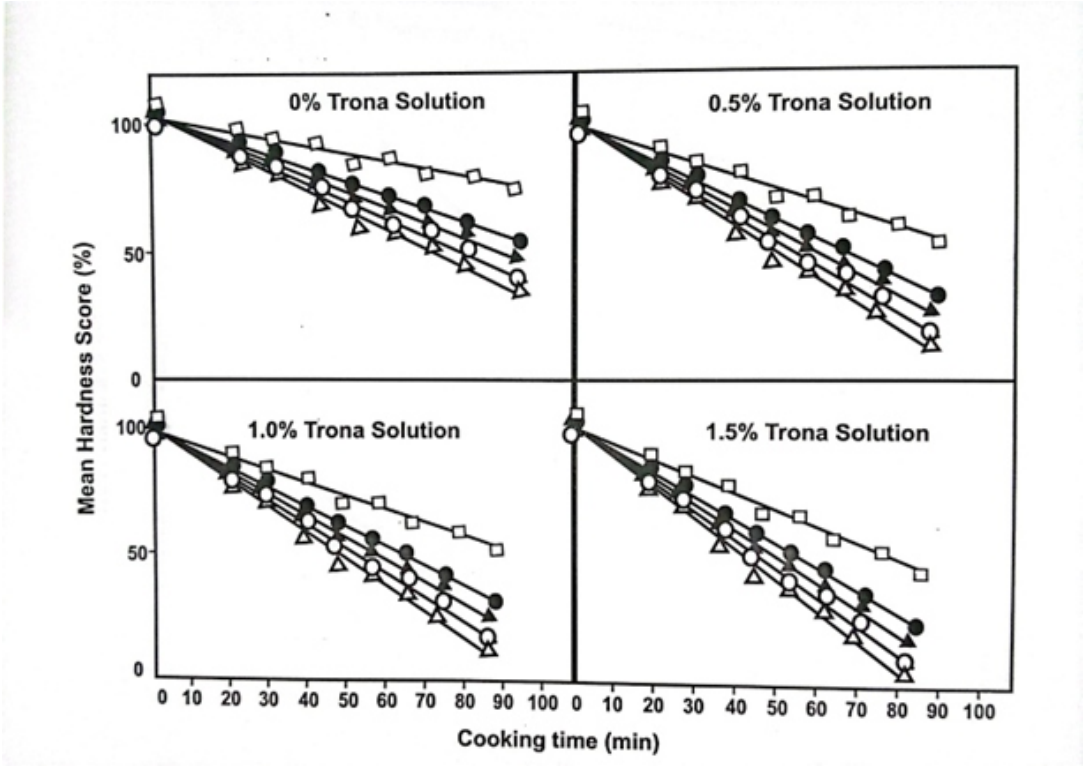


Figure 1: Zero order Plots of mean sensory scores for texture versus cooking time of African yam bean seeds at 80 (□), 85(○), 90(▲), 95(Δ), 100 (●)^{0}C respectively as influenced by trona concentrations. (Each result is mean of triplicate determinations)

Table 1: Subjective measurements derived parameters for cooking of AYB seeds.

Derived Parameter	Cooking medium trona concentration (%)			
	0	**0.5**	**1.0**	**1.5**
(min^{-1})	0.1033 – 0.1253	0.1116 - 0.1320	0.1082 -0.1624	0.1227 -0.212
·value(min^{-1})	78.4 - 64.5	72.6 – 61.4	74.1 – 50.0	66.0 – 38.3
(min)	58 - 47.9	53.8 – 45.5	50.1 – 37	48.9 – 38.3
ocess order	0.74D	0.74D	0.74D	0.74D
value (^0C)	39	37.7	24.4	16.9
$_{10}$	1.5	1.5	1.5	1.5

tc = cook value (time for doneness), D = decima reduction time, Q_{10} = temperature quotent, k = thermal soften reaction rate constant. (Each result is mean of triplicate determination)

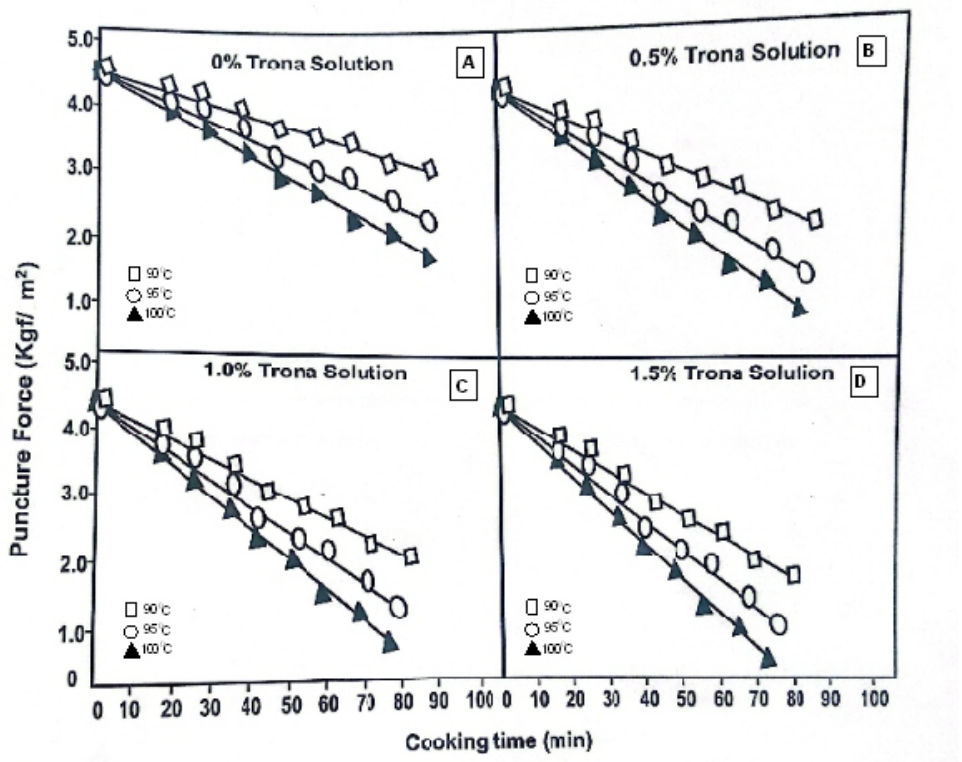


Figure 2: Plots of puncture force versus cooking time of African yam bean seeds at 90 (□), 95(○) and 100 ( ) ^0C respectively as influenced by trona concentrations. Results are mean val ues of triplicate determinatio

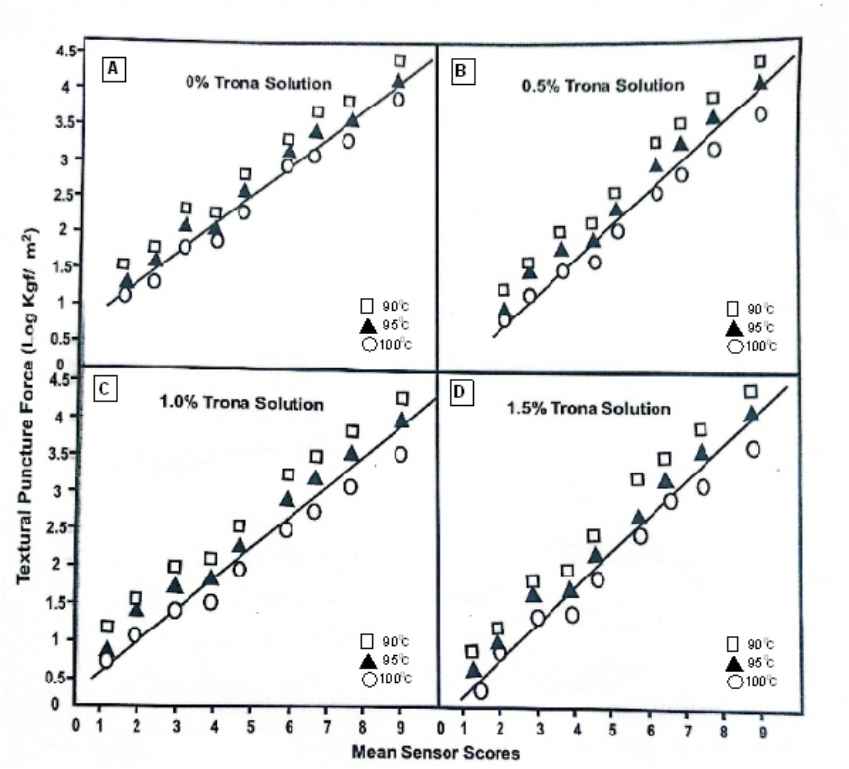


Figure 3: Principal component relationship between puncture force and mean sensor scores for conventional cooking of African yam bean at 90 (□), 95 (▲) and 100 ^{0}C (○) respectively as infleuenced by trona concentrations. Results are mean values of triplicate determination.

Table 2: Subjective measurements derived parameters for cooking of AYB seeds.

erived ırameter	Cooking medium trona concentration (%)			
	0	**0.5**	**1.0**	**1.5**
(min^{-1})	0.1033 – 0.1253	0.1116 - 0.1320	0.1082-0.1624	0.1227-0.212
-value(min^{-1})	78.4 - 64.5	72.6 – 61.4	74.1 – 50.0	66.0 – 38.3
(min)	58 - 47.9	53.8 – 45.5	50.1 – 37	48.9 – 38.3
ocess order	0.74D	0.74D	0.74D	0.74D
value (^{0}C)	39	37.7	24.4	16.9
10	1.5	1.5	1.5	1.5

tc = cook value (time for doneness), D = decima reduction time, Q_{10} = temperature quotent, k = thermal soften reaction rate constant. (Each result is mean of triplicate determination)

5.0 Conclusion and Recommendations

Subjective evaluation of the kinetics of thermal softening of AYB in heating medium trona concentration followed a zero-order kinetic model. The appropriate cooking times in 0.5%, 1.0% and 1.5% reduced cooking time of the dark brown seeds (DBS) of AYB cultivars by a factor of 1.5 to 2 during cooking at 80-100^{o} C. Adequate description on temperature dependence of Z-values, D-values, order of process and Q_{10} values of thermal softening kinetics was provided. Objective evaluation of thermal softening for changes in puncture force with cooking time of AYB in heating medium trona concentrations followed a first order kinetic model. The temperature dependence of this mechanism is similar to that for the texture in subjective measurements. The equations developed in this study which could be summarized in the following equation: F= A + B (X). This equation is a reflection of the actual situation of the process at various trona concentrations of the heating medium.

Pearson correlation between the principal components of sensory texture scores and Puncture force showing a highly positive correlation ($r^2 > 0.96$) was mathematically established. The relationship between texture and puncture force curves could be used to predict the behavior AYB seeds during cooking as an indication of the sensory texture of the cooked seeds.

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