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Classification and Quality Analysis of Rice Grain Based on Dimensional Measurement During Hydrothermal Treatment

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Abstract — *The shape and dimensional appearance of rice kernels have a significant role in their classification. In this research, various dimensional parameters of rice grain have been measured and analyzed for their gradation using the Decision Tree Learning model, and also the grain samples have been treated through a typical Hydrothermal method for determining the characteristics related to its quality. Image processing techniques have been used for such measurement, and eight Indian rice varieties with low to high amylose content (15%–28% d.b.) have been chosen for the experimentation. Dimensional changes of rice kernel during Hydrothermal treatment have been modeled mathematically, and from the model equation, a new parameter termed the average logistic growth rate (K_{Avg}) has been obtained. It has been observed that the average logistic growth rate of the rice kernel is negatively correlated with its amylose content (Correlation coefficient -0.9618) and cooking time for food preparation (Correlation coefficient -0.9499), indicating a strong relationship with rice quality. All the experimental observations finally confirm that the combined Decision Tree Learning model and the mathematical model of rice grain growth during Hydrothermal treatment for grain quality analysis is a novel idea for getting a more precise classification of rice.*

Keywords — *Classification by Decision Tree Learning model, Dimensional changes of rice, Hydrothermal treatment, Logistic growth rate, Mathematical model.*

I. INTRODUCTION

Among all food grains, rice *(Oryza sativa* L.*)* has special importance in the global market because it is the most consumed and favorite foodstuff across the world. In the present decade, many researchers have tried to present computer vision-based non-destructive methods for the identification and quality gradation of food grains. The appearance of rice kernels like long, short, medium have been measured by digital image processing [1, 2] and finally classified the dry grains using machine learning. Though this study has some drawbacks in the case of source of light, inspection system, image analysis technique, it gives an idea of rice quality measurement by appearance. Classification and identification of rice grain have been performed through feature extraction and image processing with neural network technique [3]. Rice grain quality classification with respect to broken rice has been done using morphological methods based on shape descriptors and geometric features [4, 5]. Morphology of wheat samples has been identified and distinguished on the basis of differences in geometric and shape parameters using image processing [6]. The rice milling system of classification has been developed, and the color of the paddy has been identified for computing the time of the milling process through the segregation channel [7].

Physical characteristics of rice granules have been determined and graded by the canny edge detection technique [8]. Researches have been analyzed physical and chemical property of rice grains to study the quality. But the review process and applied image processing method are not consistent. Rice has been classified depending on the size, shape, cracks, and chalkiness of the grain [9], and also various grading systems such as the K-Nearest Neighbour (KNN) classifier, Support Vector Machine (SVM), etc. have been applied for the dry rice grains.

Dimensional features like length, width, projected area, perimeter, and physiochemical properties of milled rice have been reviewed with the time of soaking by image analysis [10], and the dimensional changes of the rice with moisture content during soaking have been measured. Separately, changes in the dimension of kernels with time during cooking have been measured and characterized by deriving a mathematical model [11], but a quality aspect of rice has not been discussed here.

Cooked rice preparation has also been studied with respect to quality, and in this line quality progression of Pusa Basmati rice has been analyzed [12] to study its quality aspect with respect to the traditional hydrothermal method. Parboiling of rice has been studied to affect the degree of starch gelatinization [13], which is related to rice color and hardness of parboiled rice grain, but nonparboiled rice grain characteristics have not been measured here, and no quality classification have been done by the derived relations. Parboiled rice cooking quality and various characteristics have been studied on the basis of different types of physicochemical attributes, proximate content, vitamins, and minerals and then compared with milled rice [14]. Image processing techniques using an extended maxima operator have been used to measure the chalky area in the rice kernel [15]. Grain dimensions, chalky, and color have been analyzed to classify rice grains in the initial dry stage by a visual inspection system. Efficient rice cooking methods have been analyzed to minimize energy utilization [16].

The kinetics of rice cooking preparation have been studied and proposed as an effective scientific way of rice preparation while containing its food quality. Rice seed germination evaluation systems have been developed for germination prediction by using digital image processing and a machine learning approach [17].

This work has been applied to Thai rice by different feature extraction. Physicochemical properties like starch, gelatinization of rice kernels have been reviewed during cooking [18], and in this study, quality breeding of rice and its use have been investigated for waxy rice seed. If the amylose content of the rice sample is low, its Glycemic index is high, the rice cooks moist and sticky [19]. The cooking and eating quality of various rice samples have been evaluated through different parameter analyses [20], and rice grain elongation during cooking and water absorption have been studied.

Models for the analysis of moisture absorption have been done [21] to determine the moisture vs. time relationship of milk powder and rice through a graphical representation. The mathematical model has been fitted with the absorption curve for the potential implication in absorption data. A nonlinear classification system of model equation for the observation of experimental results has been presented in [22]. Classification of diseases has been evaluated by Image processing and machine learning classifiers [23]. Image datasets of the different plant leaves have been supervised through various features extraction for disease identification.

Classification and Regression Tree methods have been used for statistical learning techniques to compute classification rules [24]. The advantages of the classification approach in the decision tree algorithm of machine learning have been analyzed [25, 26] and compared with other methods. The various approach of decision tree algorithm has been considered to determine the acceptance of the learning strategy in large data analysis [27]. Classification techniques over the decision tree learning process have been studied [28], and a supervised learning system is used for classification by following the tree-structured data arrangement. The coefficient R^2 for standard measurement of goodness of fit for the mathematical model has been evaluated [29]. The principle of Regression analysis is a statistical approach to determine the relationship among dependent, independent, and predictor variables [30], and the application of regression analysis has been discussed with its constraints of applications.

The aforesaid presented articles are based on the measurement of morphological parameters of different rice varieties using image processing and subsequent observation on quality aspects. In most cases, dry rice samples have been taken for experimentation. A few articles have considered the cooked condition of rice for different measurements, and only one has described the soaking condition of rice. It is observed that both the dry and cooked conditions of the same sample have not been studied for classification and quality analysis, and also, the hydrothermal method of cooked rice preparation has not yet been related to quality analysis. The fact is that customers generally choose the rice quality during purchase in dry condition and finally evaluate the quality after cooking to consume as food.

In the present work, both dry and cooked rice samples have been considered for classification and quality determination using Decision Tree Learning Model. Also, dimensional changes of rice kernel during its preparation as food through hydrothermal treatment have been measured using the image processing technique. The growth of rice during such treatment has been analyzed and modeled mathematically. From this model, a new key parameter named average logistic growth rate (k_{Avg}) of kernel has been obtained, which helps to analyze the quality of rice sample as cooked food more precisely. It has been observed that rice having the same quality grade through a developed classification strategy can be further analyzed in the cooked condition on the basis of their average logistic growth rate during their hydrothermal treatment. This paper has addressed two problem statements:

1. Classification of both dry and cooked rice grain samples using the proposed Decision Tree Learning Model on the basis of customers' views.
2. Measurement of rice grain dimensional change during its preparation as cooked food through hydrothermal treatment and hence evaluation of a parameter called 'logistic growth rate' to get more precise quality analysis.

The rest of the paper is organized as follows. Section 2 describes the proposed model, and section 3 shows the materials and detailed methods followed in the present work, Section 4 explains the experimental results and discussions, and Section 5 highlights the main conclusions of the concerned work.

II. PROPOSED MODEL

In the present work, rice grain quality determination has been performed on the basis of two models such as (i) classification model for quality gradation and (ii) mathematical model of rice grain growth during its hydrothermal treatment.

A. Classification Model for Quality Gradation

Classification of both dry and cooked rice grains has been done using the Decision Tree Learning Model which is a predictive algorithm in the field of machine learning. This classification has been done by measuring kernel length (L), width (W), area (A), and perimeter (P) and then determining seven numbers of derived parameters as listed in Table I.

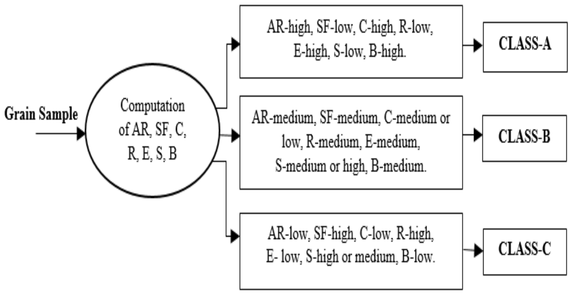

Fig 1: Proposed model for classification of rice kernel

In the proposed model, the dimensional appearance of rice kernel as per customer's choice has been taken into account in deciding three grades like Class A, Class B, and Class C, as shown in Fig. 1.

TABLE I
PARAMETERS OF RICE KERNEL SELECTED FOR DESIGNING CLASSIFICATION MODEL

Parameters selected for classification model	Expression
Aspect Ratio (AR): Ratio of length and width	$\frac{L}{W}$
Shape Factor (SF): Shape factor (appearance)	$\frac{A}{L \times W}$
Compactness (C): Closeness and boundness	$\frac{P^2}{A}$
Roundness (R): Approach to the perfect circle	$\frac{4\pi * A}{P^2}$
Eccentricity (E): Ratio between foci (2c) and the length of the major axis (2a)	$\frac{c}{a}$
Solidity (S): Ratio of projected area and area of the convex hull.	$\frac{A}{Area\ of\ Convex\ h}$
The bounding box (B): Rectangle with the smallest possible surface area	$L * W$

During classification, the proposed model has been trained with respect to the measured data from known rice kernel dimensions as training data, and then it has been tested using test data set from the measurement of unknown rice samples as shown in Fig. 2.

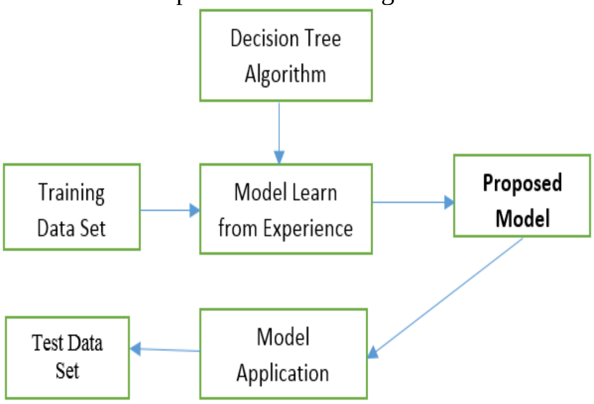

Fig 2: Training and testing of the proposed model for Classification

B. Mathematical Model of Rice Grain Growth during its Hydrothermal Treatment

The rice kernel growth with respect to time observed in the present work during its preparation as cooked food through hydrothermal treatment has similarity with the 'S' shaped curve, called logistic sigmoid curve, also known as Richard's curve. The sigmoid logistic curve or logistic function with 'S' shape is described by Equation (1) as follows,

$$f(x) = \frac{l}{1+e^{-k(x-x_0)}} \tag{1}$$

Where l is the maximum value of the curve, x_0 is the x value of the sigmoid midpoint, and k is the logistic growth rate or steepness of the curve. On the basis of this observation, a general mathematical model of rice grain growth as a function of time has been proposed in the present work as represented by (2),

$$f(t) = \frac{D}{1+e^{-k(tn-t0)}} \tag{2}$$

Where, $f(t) = \frac{(D_t-D_0)}{D_0}$, (3)

And, $D = \frac{(D_e-D_0)}{D_0}$ (4)

Combining Equations (2), (3), and (4), the nature of kernel growth with respect to time during its hydrothermal treatment has been described by general model Equation (5) for all parboiled and non-parboiled rice samples taken in the present work.

$$\frac{(Dt-D0)}{D0} = \left(\frac{De-D0}{D0}\right) * \frac{1}{1+e^{-k(tn-t0)}} \tag{5}$$

The generalized rice kernel growth model as indicated by(5) has been represented for expressing the kernel growth in L, W, A, and P respectively as,

$$\frac{L_t-L_0}{L_0} = \left(\frac{L_e-L_0}{L_0}\right) * \frac{1}{1+e^{-k_L(tn-t0)}}$$
(6)

$$\frac{W_t-W_0}{W_0} = \left(\frac{W_e-W_0}{W_0}\right) * \frac{1}{1+e^{-k_W(tn-t0)}}$$
(7)

$$\frac{A_t-A_0}{A_0} = \left(\frac{A_e-A_0}{A_0}\right) * \frac{1}{1+e^{-k_A(tn-t0)}}$$
(8)

$$\frac{P_t-P_0}{P_0} = \left(\frac{P_e-P_0}{P_0}\right) * \frac{1}{1+e^{-k_P(tn-t0)}}$$
(9)

Where fractional growth in L, W, A, and P is a function of time and given by,

$\Delta L(t) = \frac{L_t-L_0}{L_0}$, $\Delta W(t) = \frac{W_t-W_0}{W_0}$,
$\Delta A(t) = \frac{A_t-A_0}{A_0}$, and $\Delta P(t) = \frac{P_t-P_0}{P_0}$.

Maximum fractional growth in L, W, A, and P of kernels are indicated as,

$\Delta L(max) = \frac{L_e-L_0}{L_0}$, $\Delta W(max) = \frac{W_e-W_0}{W_0}$,
$\Delta A(max) = \frac{A_e-A_0}{A_0}$, and $\Delta P(max) = \frac{P_e-P_0}{P_0}$.

The proposed model Equations (6), (7), (8), and (9) developed in the present work for describing the kernel growth during hydrothermal treatment has been taken into account to determine the rice grain quality.

Nomenclature

A_0	Initial projected area	L_0	Initial length
A_e	Highest elongated projected area	L_t	Length at instant t
A_t	The area at instant t	L_e	Highest elongated length
D	The maximum fractional change in dimension	P_0	Initial perimeter
D_0	Initial dimensional value	P_e	Highest elongated perimeter
D_e	Highest elongated dimension	P_t	Perimeter at instant t
D_t	Dimension at instant t	t	Time instant of observation
k_L	The logistic growth rate in length	t_0	Time at the sigmoid midpoint, as a fraction of total time
k_W	The logistic growth rate in width	t_n	Instantaneous time of observation as a fraction of total time
k_A	The logistic growth rate in the projected area	W_e	Highest elongated width
k_P	The logistic growth rate in perimeter	W_0	Initial width
k_{Avg}	Average logistic growth rate	W_t	Width at instant t

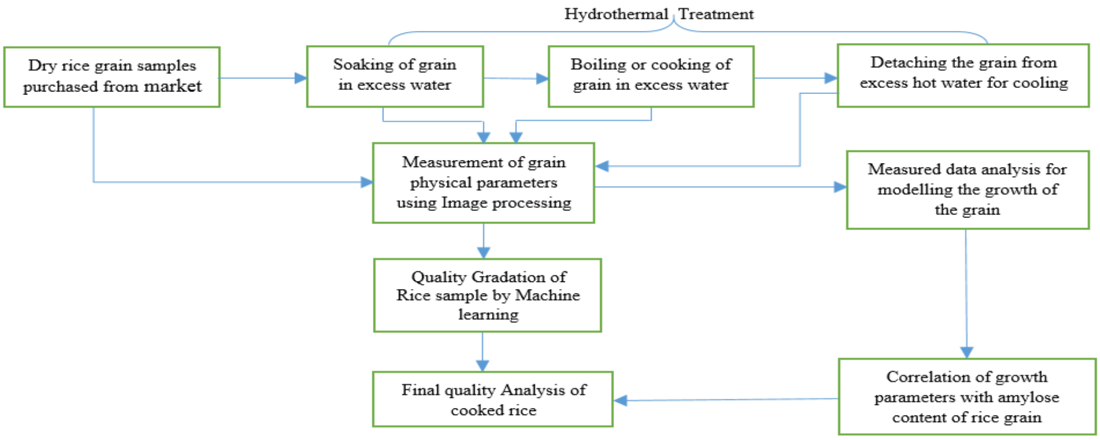

Fig 3: General block diagram of the present experiment

III. MATERIALS AND METHOD

Eight Indian varieties of rice samples have been taken for dimensional measurement through continuous hydrothermal treatment for mathematical modeling and quality classification.

A. Materials

In the present work, five parboiled rice with high and medium amylose content and three non-parboiled rice with low amylose content have been taken for experimentation. The name and detail specification of samples are indicated in Table II. No cracks were there within the samples. Distilled water has been used for the hydrothermal treatment of rice samples.

TABLE II
EIGHT INDIAN RICE SAMPLES WERE CHOSEN FOR EXPERIMENTATION

Rice Sample	Amylose Content (%) d.b.	Market Price Rs. /Kg
Bas 370 (Parboiled, long shape)	23.3	70-80
IG-Basmati (Parboiled, long shape)	25.5	75-85
IR 36 (Parboiled, medium shape)	27.1	40-50
Ratna (Parboiled, medium shape)	23.1	35-45
Swarna (Parboiled, short shape)	22.5	25-35
Gobindavog (Non-parboiled, short shape)	15.5	80-90
Atap (Non-parboiled, short shape)	17.1	30-40
New Atap (Non-parboiled, short shape)	19.5	35-45

B. Method of Experiment

The methodology followed in the present research, such as three stages of continuous hydrothermal treatment, points of measurement of grain dimension, and data analysis for classification or gradation are shown in the general block diagram, Fig. 3. The experiment has been started with dimensional measurement of dry samples. This has been done by capturing the images of the rice kernels using high quality digital dual camera (13 megapixels + 2 megapixels) with a resolution of 720 × 1520 pixels. Proper lighting and fixed distance (14 cm.) between the camera and samples have been considered for taking all the images.

To start with the hydrothermal treatment, as shown in Fig. 4, about 10 gm of rice samples have been taken with 100 ml of distilled water within a 250 ml container for water absorption at room temperature (22°-25°C) and such soaking has been allowed through 30 minutes as shown in Fig. 4.a. After that samples have been heated in same excess water for cooking as shown in Fig. 4.b. Boiling has been continued up to the occurrence of the highest elongation of the kernels, which depends on its gelatinization characteristics. The parboiled samples have been heated up to 50 min, and non-parboiled samples have been heated up to 20 min. In the next stage, grains have been separated from hot water to observe retrogradation effect as shown in Fig. 4.c Images have been taken at 10 min intervals during the above hydrothermal treatment, and at a time 30 to 35 numbers of rice kernels, not connected to each other have been taken for dimensional measurement using image processing technique as indicated in Fig. 4.d.

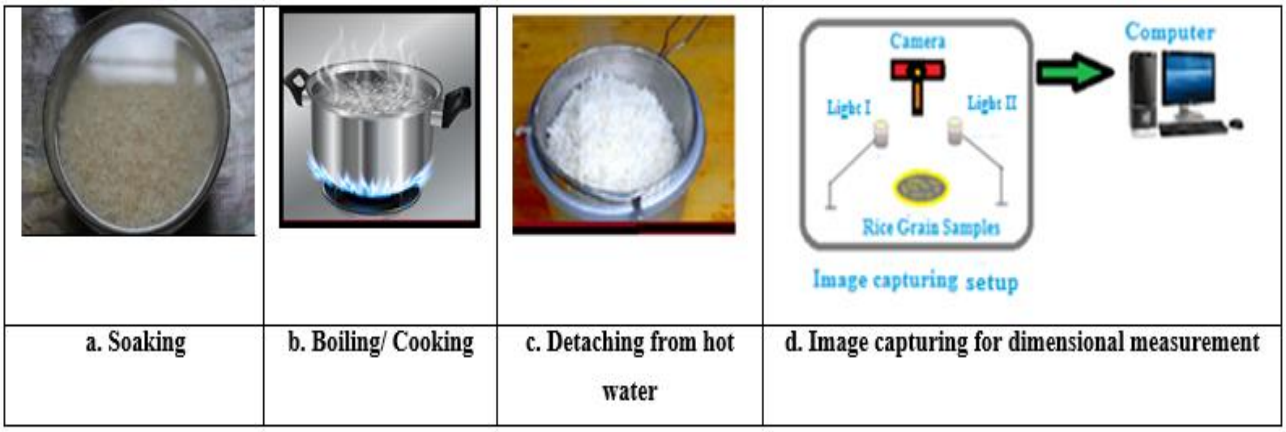

Fig 4: Three phases of hydrothermal treatment and image capturing system

C. Method of Dimensional Measurement by Image Analysis

Dimensional parameters such as length (L), width (W), projected area (A), and perimeter (P) of rice kernel have been measured using image processing. The acquired kernel images in RGB format have been processed to get a grayscale image that has been smoothed using a Gaussian filter. Background subtraction techniques have been used to extract the foreground of the images for object recognition. Image segmentation has been applied for finding the fixed intensity value in the image. Then edge detection has been done for detecting horizontal, vertical, and diagonal edges. Lastly, image indexing has been done for the retrieval of morphological characteristics. Dimensions of the indexed images have been measured and analyzed for the distinct kernel. Another derived parameters like AR, SF, C, R, E, S, and B related to kernel dimension, as described in Table I, have also been measured for developing the classification model.

D. Method of Data Fitting

Measurement data corresponding to dimensional changes of rice kernel with time during its hydrothermal treatment has been analyzed to develop the proposed mathematical model with a view to search for quality.

The goodness of fitting the data with model equation has been evaluated by determining Regression coefficient (R^2), Root Mean Square Error (RMSE), and Chi-square fitting value (χ^2) as shown in Equations (10), (11), and (12).

Regression coefficient, $R^2 = 1 - \frac{\sum_{i=1}^{N}(y_i - y_{fit})^2}{\sum_{i=1}^{N}(y_i - y_{mean})^2}$

(10)

Where, y_i is the experimental value; y_{fit} is the estimated or fitted data value; y_{mean} is the mean of y_i; N, the total number of data present in each sample; and i=1, 2……, N.

$$RMSE = \frac{1}{N}\sqrt{\sum_{i=1}^{N}(y_{observed} - y_{estimated})^2}$$

(11)

Where, $y_{observed}$ is the experimental value; $y_{estimated}$ Is the estimated or fitted data value; N is the total number of data present in each sample; and i=1, 2, …… N.

Chi square (χ^2) = $\frac{\sum_{i=1}^{N}(O_i - E_i)^2}{Ei}$

(12)

Where, O_i is the ith observation, E_i Is the estimated data from the model equation, *N* is the size of the sample.

IV. RESULTS AND DISCUSSIONS

Experimental results with respect to both hydrothermal treatment of rice grain and classification using the decision tree learning model have been analyzed for final quality determination.

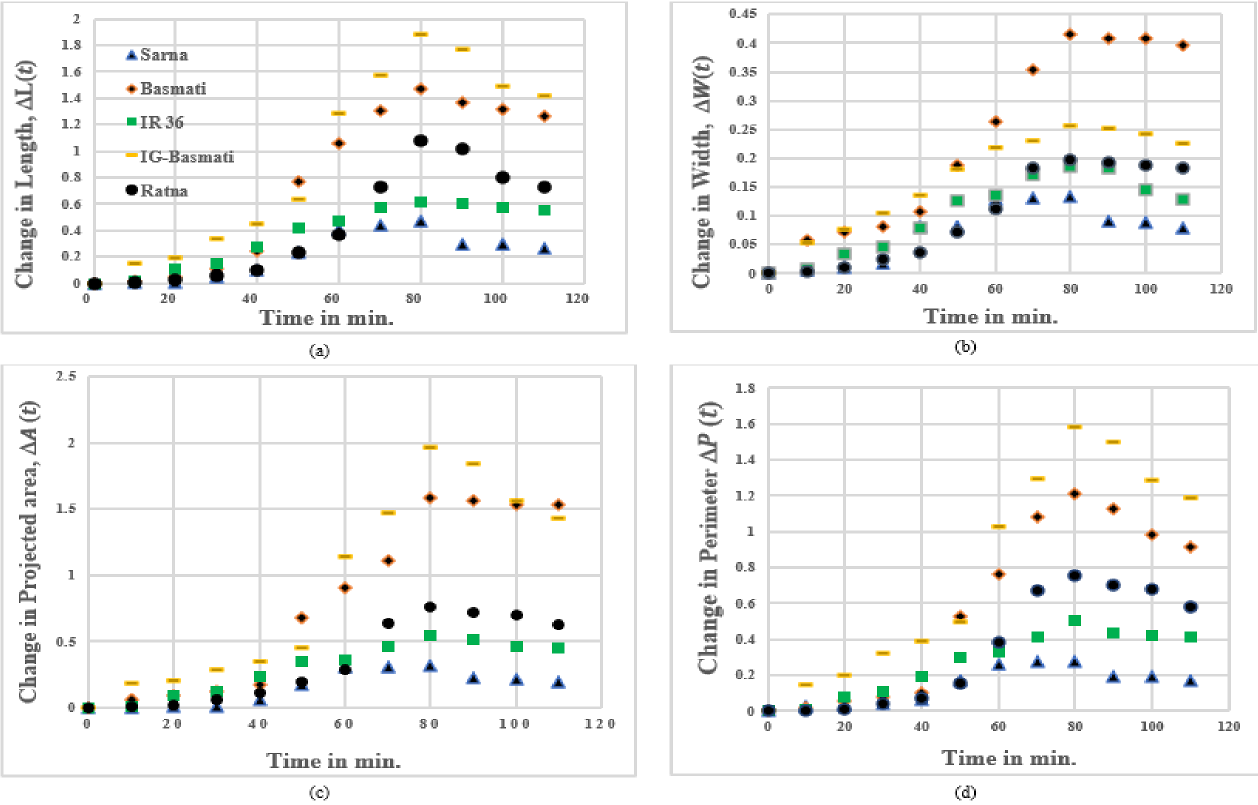

Fig 5: Fractional changes in (a) L, (b) W, (c) A, and (d) P for parboiled rice with respect to time

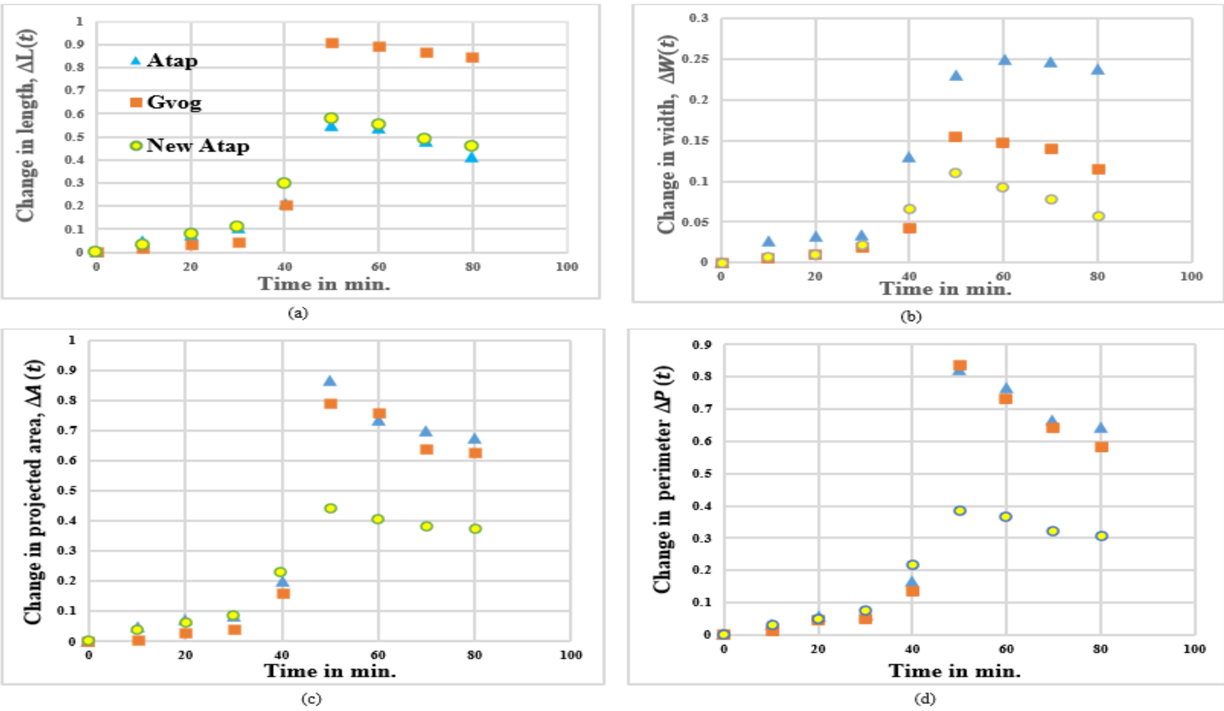

Fig 6: Fractional change in (a) L, (b) W, (c) A, and (d) P for non- parboiled rice with respect to time

A. Result of Hydrothermal Treatment

Parboiled and non-parboiled rice samples have been taken from the market in ambient conditions for experimentation, and their physical parameters like L, W, A, and P have been measured by image processing methodology, as mentioned in the previous section. Measurement of L, W, A, and P of kernels has been done at dry condition, during hydrothermal treatment, and at the final cooked stage.

Fractional changes in rice grain dimensions such as $\Delta L(t)$, $\Delta W(t)$, $\Delta A(t)$, and $\Delta P(t)$ of both parboiled and non-parboiled samples during their hydrothermal treatment have been plotted with respect to time as shown in Fig. 5 and Fig. 6.

It is observed that the growth rate of rice during soaking is much less compared to boiling, and at the end of boiling, maximum expansion occurs when gelatinization starts. After the highest growth, when rice kernels are separated from hot water for cooling, their dimensions are not increasing rather decreasing slightly and then saturates, which is the retrogradation effect.

The time of maximum expansion during boiling for non-parboiled rice samples is less than the parboiled rice. The nature of such hydrothermal characteristics of the rice kernel growth has been described by the proposed mathematical model Equations (6), (7), (8), and (9) developed in the present research.

B. *Evaluation of Fitness of Model Equation with Experimental data*

The goodness of fit of model equations (6), (7), (8), and (9) with experimental data has been determined in terms of evaluation of Regression coefficient (R^2), Root Mean Square Error (RMSE), and Chi-square value (χ^2) as described by (10), (11) and (12). The values of R^2, RMSE, χ^2 and fitness (%) for the dimensional attribute like $L, W, A,$ and P are shown in Tables III-VI.

It is obtained that for all dimensions, L, W, A and $P,$ the value of RMSE is < 0.01, the range of R^2 is 0.93-0.99, and the range of Chi-square fitness is 96.5% - 99.9%. These results establish a good fit of the experimental data with the model equation for rice samples.

TABLE III
GOODNESS OF FIT IN LENGTH, $\Delta L(t)$

Sample	ΔL(max)	RMSE	R^2	Chi Square	Fitness (%)
Bas 370	1.47	0.004	0.97	0.13	99.9
IG-Basmati	1.89	0.008	0.96	0.636	99.9
IR 36	0.88	0.002	0.96	0.126	99.9
Ratna	1.08	0.002	0.97	0.086	99.9
Swarna	0.47	0.004	0.98	0.032	99.9
Gobindavog	1.12	0.002	0.97	0.241	99.9
Atap	0.62	0.001	0.94	2.32	97.5
New Atap	0.58	0.001	0.94	0.37	99.9

TABLE IV
GOODNESS OF FIT IN WIDTH, $\Delta W(t)$

Sample	ΔW(max)	RMSE	R^2	Chi-Square	Fitness (%)
Bas 370	0.39	0.0004	0.96	0.4005	99.9
IG-Basmati	0.26	0.0001	0.98	0.0205	99.9
IR 36	0.18	0.0001	0.99	0.011	99.9
Ratna	0.20	0.0001	0.98	0.028	99.9
Swarna	0.18	0.0001	0.99	0.0103	99.9
Gobindavog	0.15	0.0001	0.96	0.431	99.9
Atap	0.23	0.0002	0.93	0.387	99.9
New Atap	0.11	0.00003	0.95	0.023	99.9

TABLE V
GOODNESS OF FIT IN PROJECTED AREA, $\Delta A(t)$

Sample	ΔA(max)	RMSE	R^2	Chi-Square	Fitness (%)
Bas 370	1.58	0.003	0.98	0.219	99.9
IG-Basmati	1.97	0.011	0.95	0.812	99.9
IR 36	0.55	0.0004	0.97	0.065	99.9
Ratna	0.76	0.002	0.96	0.148	99.9
Swarna	0.32	0.0003	0.96	0.044	99.9
Gobindavog	0.79	0.003	0.95	3.26	96.5
Atap	0.86	0.001	0.97	1.707	99.5
New Atap	0.44	0.001	0.94	0.418	99.9

TABLE VI
GOODNESS OF FIT IN PERIMETER, $\Delta P(t)$

Sample	ΔP(max)	RMSE	R^2	Chi-Square	Fitness (%)
Bas 370	1.21	0.005	0.95	0.146	99.9
IG-Basmati	1.58	0.008	0.95	0.449	99.9
IR 36	0.50	0.001	0.96	0.079	99.9
Ratna	0.76	0.001	0.97	0.090	99.9
Swarna	0.27	0.0002	0.95	0.038	99.9
Gobindavog	0.83	0.002	0.95	0.827	99.5
Atap	0.82	0.001	0.96	0.179	99.9
New Atap	0.38	0.0003	0.96	0.386	99.9

C. *Evaluation of Model Parameter for Quality Analysis*

In the present work, the logistic growth rates, k_L, k_W, k_A, and k_P as mentioned in (6), (7), (8), and (9) as model parameters corresponding to L, W, A, and P respectively, have been computed using optimization technique during fitting the experimental data with the model equation. The average of these logistic growth rates, k_L, k_W, k_A, and k_P for each sample, have been computed and termed as average logistic growth rate k_{Avg}, which has been noted as a typical characteristic of that sample as shown in Table VII.

TABLE VII
AMYLOSE CONTENT AND AVERAGE LOGISTIC GROWTH RATE, K_{AVG} OF RICE SAMPLES

Rice Sample	k_L	k_W	k_A	k_P	Average logistic growth rate k_{Avg}
Bas 370	11.95	9.77	10.39	11.98	11.02
IG Basmati	9.44	8.52	8.90	8.39	8.81
IR 36	7.63	8.95	7.47	7.51	7.89
Ratna	10.09	12.13	10.97	14.59	11.94
Swarna	13.44	11.23	13.33	10.28	12.07
Gobindavog	19.19	20.06	28.08	20.95	22.07
Atap	15.81	17.08	18.55	15.27	16.68
New Atap	14.85	12.08	13.20	14.64	13.69

The relation between k_{Avg} and amylose content of rice grain sample has been observed in Fig. 7, which shows a negative correlation (coefficient–0.9618). This indicates that as the amylose content of rice grain decreases, its average logistic growth rate increases. The physicochemical property like stickiness is found to increase with decreasing amylose content in the whole grain. So, it can be concluded that stickiness will increase with the increase in the average logistic growth rate k_{Avg} of rice samples.

It is also to be noted that stickiness is an important quality factor associated with cooked rice performance.

Thus, the average logistic growth rate k_{Avg} obtained from Table VII can act as a quality indicator of the corresponding sample with respect to its stickiness.

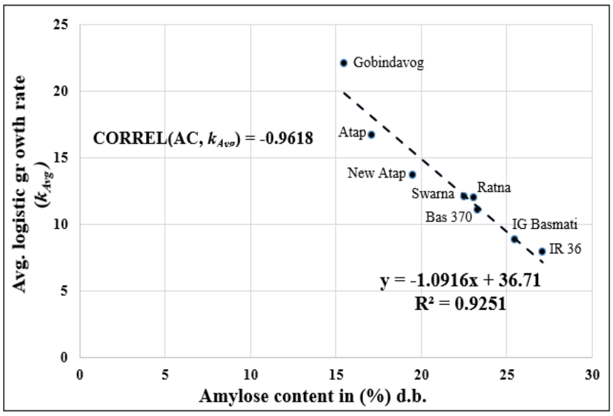

Fig 7: Relation between average logistic growth rate (k_{Avg}) and amylose content of rice samples

The relation between the maximum elongation time during hydrothermal treatment of the rice samples and average logistic growth rate (k_{Avg}) have been plotted in Fig. 8, which also shows a negative correlation (coefficient–0.9499).

This indicates that cooking time is inversely related to the average logistic growth rate (k_{Avg}) of that rice sample. Thus, fuel consumption during the preparation of rice will be lower when the average logistic growth rate (k_{Avg}) for that sample is higher.

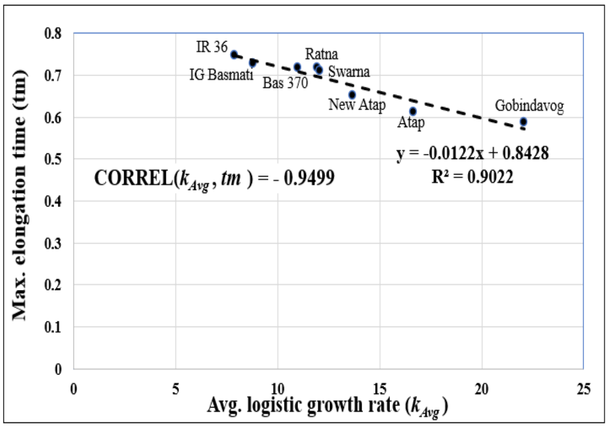

Fig 8: Relation between Maximum Elongation time and average logistic growth rate (k_{Avg})

D. Classification of Rice as per Decision Tree Learning Model

The proposed Decision Tree Learning Model as shown in Fig. 1, has been used for the classification of both dry and cooked rice samples. Derived parameters like AR, SF, C, R, E, S, and B, as mentioned in Table I, have been determined from the basic kernel dimensions like L, W, A, and P. The derived parameters are dimensionless quantities with distinct nature for individual rice samples. In-class assessment of rice, these derived parameter values have been chosen for quality classification as shown in the proposed model. The results of such classification of all samples are shown in Table VIII. It is to be noted that the cooked condition of rice samples has been classified along with the dry condition in the present work, unlike the previous works.

TABLE VIII
RICE SAMPLE CLASSIFICATION USING DECISION TREE LEARNING MODEL

Parameter	Phase of Experimentation	Categorization of Rice grain							
		Bas 370	IG-Basmati	IR 36	Ratna	Swarna	Gobindavog	Atap	NewAtap
AR	Dry	A	A	B	B	C	A	C	B
	Cooked	A	A	B	B	C	A	C	B
SF	Dry	A	A	B	B	C	A	C	B
	Cooked	A	A	B	B	C	A	C	B
C	Dry	A	B	B	B	C	B	C	B
	Cooked	A	B	B	A	C	B	C	B
R	Dry	A	B	B	B	C	B	C	B
	Cooked	A	B	B	A	C	B	C	B
E	Dry	A	A	B	B	C	A	C	C
	Cooked	A	A	B	B	C	A	C	C
S	Dry	A	A	B	B	C	A	C	C
	Cooked	A	A	B	B	C	A	C	C
B	Dry	A	A	B	B	C	A	C	A
	Cooked	A	A	C	B	C	A	B	B
Final class		A	A	B	B	C	A	C	B

The proposed learning model for classification has been tested on three unknown samples during both dry and cooked conditions as test data set as shown in Table IX. The gradation has been obtained from the experimental result and is in parity with the quality detected by the market price and customer choice.

It has been observed that the developed learning model accurately graded unknown samples 40 times within 42 times of test case.

TABLE IX
UNKNOWN SAMPLE CLASSIFICATION BY PROPOSED MODEL

Paramet er	Phase of Experim entation	Categorization of Unknown Sample		
		Rice-1	Rice-2	Rice-3
AR	Dry	C	B	A
	Cooked	C	B	A
SF	Dry	C	B	A
	Cooked	C	A	A
C	Dry	C	B	A
	Cooked	C	B	A
R	Dry	C	B	A
	Cooked	B	B	A
E	Dry	C	B	A

	Cooked	C	B	A
S	Dry	C	B	A
	Cooked	C	B	A
B	Dry	C	B	A
	Cooked	C	B	A
Final class		C	B	A

The performance of the proposed model has been computed from the test case, as shown in Table X. The accuracy of the system is 95.24%.

TABLE X
ACCURACY OF THE PROPOSED LEARNING MODEL

Test cases	True	False	Accuracy (%)	Error (%)
42	40	2	95.24	4.76

E. Final Quality Analysis of Rice through Decision Tree Learning Model and Mathematical Model

In the present observation, the impact of a new parameter called average logistic growth rate, k_{Avg} obtained from a mathematical model.

TABLE XI
FINAL QUALITY ANALYSIS: COMBINED DECISION TREE LEARNING MODEL AND MATHEMATICAL MODEL

Rice Sample	'k_{Avg}' from Mathematical Model	Grade from Decision Tree Model	Remarks on the final quality aspect
Bas 370	11.02	A	Both rice samples have an A grade. IG Basmati having a lower 'k_{Avg}' value will be less sticky than Bas 370 having a higher 'k_{Avg}' value. The cooking time of IG Basmati will be more compared to Bas 370.
IG Basmati	8.81	A	
IR 36	7.89	B	Both samples have a B grade, but IR 36 having a lower 'k_{Avg}' value will be less sticky than Ratna having a higher 'k_{Avg}' value. The cooking time of IR 36 will be more compared to Ratna.
Ratna	11.94	B	
Swarna	12.07	C	'k_{Avg}' value is moderately high for Swarna. Stickiness is much higher than Bas 370, IG Basmati, IR 36, and Ratna. Also, the Cooking time of Swarna is lower than the above samples.
Gobindavog	22.07	A	All these non-parboiled rice have a much higher 'k_{Avg}' value compared to parboiled rice. This indicates that non-parboiled cooked rice will be stickier in nature compared to parboiled rice. The cooking time of these samples will be much less compared to parboiled samples.
Atap	16.68	C	
New Atap	13.69	B	

Rice kernel growth during hydrothermal treatment has been noticed on the classification of rice grain using Decision Tree Learning Model. Summary of these observations and final quality analysis are shown in Table XI.

It is observed that when the Decision Tree Learning Model gives the same quality gradation of two or more samples, the average logistic growth rate, k_{Avg} from the mathematical model, can dictate further quality comparison among those samples with respect to their stickiness property and cooking time. Cooking time is again related to fuel consumption for rice preparation. In the previous methods, quality classification of rice grain was done on the physical appearance of dry rice only, and also, the mathematical model of rice grain growth during hydrothermal treatment has not yet been considered for quality analysis.

Unlike the previous methods, in the present work, both dry and cooked rice dimensions have been measured and analyzed for quality determination using the proposed Decision Tree Learning Model.

In addition to the classification model, the mathematical model of rice grain growth during hydrothermal treatment of rice grain sample has been proposed and analyzed to determine a typical parameter called average logistic growth rate, k_{Avg}, for quality analysis. Comparison between parboiled and non-parboiled rice samples can also be done using the present method. This approach of classification combined with hydrothermal treatment is a new and novel idea for better quality analysis of rice grain.

The average logistic growth rate, k_{Avg}, computed from the proposed mathematical model can be related to other various physicochemical properties of rice grain apart from stickiness, and this will be done in the future study.

V. CONCLUSIONS

It is known that customers generally determine the rice quality by observing its appearance during purchase in dry condition and then as food in cooked condition. So, the classification of rice done only on the basis of its physical dimension in dry conditions can't dictate its complete quality aspect. With this concept, in the present work, rice quality classification based on their physical dimensional parameters has been performed both in dry and cooked conditions to get the overall classification using Decision Tree Learning Model.

In addition to that, a new approach such as modeling rice grain dimensional changes with time during its preparation as cooked food through hydrothermal treatment has been successfully applied to relate the average logistic growth rate (k_{Avg}) with amylose content and time of attaining maximum growth of rice, i.e., cooking time. Also, cooking time is related to the fuel consumption required for preparing cooked food.

In the present work, all the experimental observations finally help to get rigorous quality analysis of rice with respect to their stickiness property and cooking time even if for same graded samples decided by Decision Tree Learning Model. Also, the difference in the quality of parboiled and non-parboiled rice samples has been analyzed using their average logistic growth rate (K_{Avg}).

It is concluded that the classification method based on the Decision Tree Learning Model in the dry and cooked condition of rice combined with hydrothermal method during its preparation as cooked food is a new and novel idea for better quality analysis of rice in comparison to the older methods.

Application of Proposed work can be extended through the physical implementation of an automatic instrumentation system for rice classification.

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