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A Novel Machine Vision Technique for Prediction of Alkali Spreading Value in Rice

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ABSTRACT
The quality of rice is characterised by its physical & biochemical attributes. The physical attributes of rice are size, shape, colour and texture. On the other hand, biochemical attributes are assessed from cooking and eating characteristics of rice and are quantified as alkali spreading value (ASV), amylose content (AC), gel consistency (GC), grain elongation etc. The cooking quality is assessed by biochemical tests. The biochemical tests are often time-consuming and require a meticulous effort of sample preparation, storage and manual measurement. Alkali spreading value of rice represents the gelatinization temperature (GT) which is associated with the amylose content of the starch and has a negative correlation with the cooking temperature of rice. Rice variety with high ASV requires comparatively less temperature for cooking and is susceptible to insect damage. This paper proposes an automated method supplementing the manual decision-making process by implementing a computerized digital image analysis technique by using a portable flatbed scanner to objectively measure the rate of spreading during ASV testing. A new measurement index (Spreading Index) is proposed for calculating the extent of alkali spreading using digital image analysis. The machine vision solution proposed though is an approximate, rapid and effective way to determine the ASV. A higher-order polynomial curve fitting technique has been adopted for the prediction of the Spreading Index. Finally, the results show promise towards this new approach for the rapid prediction of ASV.

KEYWORDS: *Alkali Spreading Value, Gelatinization Temperature, Spreading Index, Digital Image Analysis, Polynomial Fit.*

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I. INTRODUCTION

Rice, Oryza Sativa, the staple food of nearly one-half of the world's population, occupies a pivotal role in Indian livelihood and food security systems. Rice quality is a complex attribute comprising many physical & biochemical characteristics. All consumers want the best quality that they can afford. Traditionally, the quality of rice is evaluated subjectively by a trained expert employing visual inspection and monitoring the aroma of cooked rice. Rice grain quality is largely determined by the properties of size, shape, colour and texture of rice grain, whereas the cooking and eating characteristics are influenced by the properties of gelatinization temperature, amylose content, gel consistency test and grain elongation. In addition to the dimensional traits of rice, there are some chemical quality parameters having prime importance from the export point of view. Some of the biochemical quality parameters are, (a) Alkali Spreading Value (ASV), which measure the gelatinization temperature (GT), (b) Amylose Content, (c) Elongation Ratio, (d) Gel Consistency that measures the type of cooked rice by the help of a standard table. The above parameters are measured by chemical analysis followed by visual inspection method which is subjective, time consuming, non-repeatable and depend on human perception. The alkali spreading value of whole kernel milled rice in contact with dilute alkali is a measure of gelatinization temperature which is partly associated with the amylose content of the starch. The gelatinization temperature of the endosperm starch refers to the cooking temperature at which water is absorbed and the starch granule swell irreversibly with simultaneous loss of crystallinity. When rice is treated with dilute alkali, the starch molecules present in rice start to degrade resulting in the disintegration of the grain. Depending upon the variety, the changes in grain shape may vary from no apparent effect to a completely dispersed grain. The changes are recorded manually using a seven-point scale based on which the GT range (Table-1) of the rice may be ascertained.

Table 1: Appearance-based measurement and correlation of ASV value and GT

Score	Spreading scale	Rating	GT
1-2	Kernel not affected	Low	High>74ºC
3-4	Kernel is swollen, collar complete and wide	Low intermediate	High, intermediate (71-74 ºC)
5-6	Kernel split or segmented, collar complete and wide, Kernel dispersed	Intermediate	Intermediate (70-74 ºC)
7	All kernel dispersed and intermingled	High	Low<70 ºC

The GT reflects the hardness of the endosperm and the presence of starch granule. Evidence reveals that grain with low GT is susceptible to insect damage during storage.

Barber et al. (1979) recommended two priority research areas, one was the analysis of grain quality and the other regarding the study of the properties of cooked rice [1]. The authors stated that the increase in gelatinization and swelling of rice is due to the increase of starch content in rice endosperm due to the absorption of water. However Little and Dawson (1960) suggested that even though the volume of rice increases 60 times due to the presence of starch but the rice kernel swells no more than 4 times in excess water [2]. Later, Juliano et al (1964) suggested that apart from the composition of starch and non-starch constituents, the physical structure of starch granule is even more important [3]. However, Del Rosario et al. (1968), and Evers et al. (1976) observed various arrangements of rice endosperm cells and proved that the physical properties of rice should also be taken into consideration [4], [5]. Even though various research works conducted for analyzing rice grain quality following chemical means, still more research to be done on milled rice based on its different cooking and eating qualities in a time-efficient way. The National Rice Quality Laboratory, Beaumont, TX, United States routinely tested gelatinization temperature of starch and alkali spreading value, water uptake capacity at 77°C, amylographic gelatinization and pasting characteristics, and protein content of milled rice in addition to amylose content. The International Rice Research Laboratory, Philippines, used two additional indices, gelatinization temperature and gel consistency of milled rice. The structural changes of starch granules during gelatinization has been evaluated with the light microscope and the scanning electron microscope (SEM), as reported by researchers; Miller et al., 1973 [6]; Hill and Dronzek, 1973 [7]; Chabot et al.1976 [8]; Hoseney et al., 1977 [9], 1978 [10]; Lineback and Wongsrikasem, 1980 [11]; Bowler et al., 1980 [12]; Holmes and Soeldner, 1981 [13]; Christiansen et al.1982 [14]. However, studies on the gelatinization and swelling pattern of isolated rice starch and of milled rice are limited. Little and Dawson, 1960 [2]; Bechtel and Pomeranz, 1980 [15]; Wirakartakusumah, 1981 [16]; Damir, 1985 analysed that even most of the in-situ gelatinization studies were done during the parboiling process rather than during the cooking of boiled rice [17]. Young Eun Lee (IOWA UNIVERSITY) evaluated the physicochemical properties of rice starch and milled rice to examine the relationships among them [18]. He reported the changes in the physical appearance of starch granules heated in excess water and evaluated their effects on the development of rheological properties and viscosity. He also evaluates the effects on the cooking and eating qualities of rice during heating. Du et al. (2004) reported computer vision-based image processing techniques for quantitative characterization of food based on complex size, shape, colour and texture properties [19]. Dr. Chintan K Modi and Kavindra R Jain proposed a machine vision system and a novel technique for quality evaluation of hydrothermally treated quick-cooking scented rice. They quantified the rapidity of cooking time and mechanical strength based on image processing techniques thereby developing an algorithm. Little et al. described in 1958 a rapid and easy method to evaluate the GT of rice starch granules using an alkali degradation test that relies on visual observation of the degree of dispersion of 6 grains of milled rice after immersion in 1.5 or 1.7% KOH overnight [20]. The degree of degradation evaluated visually by a human expert and compared with the samples of known behavior was expressed by a numerical score ranging from 1 (kernels not affected by alkali) to 7 (kernels completely dispersed and intermingled). Simpson et al. (1965) found a close correlation ($r = 0.80$) between the results obtained by applying this test and the GT of milled rice [21]. This method, developed for milled rice, was then modified for brown rice, including the use of 1.9% KOH and incubation overnight at 40^{o}C. Another modification of the alkali spreading test was reported by Bhattacharya and Sowbhagya (1972): they devised a 9 point score card and proposed 1.4% KOH for the test [22]. The initial score card was slightly modified and simplified for the purpose of an international cooperative test (Juliano et al., 1982) [3]. Another simplified method was reported by Bhattacharya et al. (1982) to predict GT values from the alkali scores [23].

The conventional procedure for measurement of the alkali spreading value (ASV) test is conducted in Petri plates containing six raw milled rice grains and treated with potassium hydroxide (1.7%) solution. The plates were incubated overnight at room temperature, and the scoring was done (7-point scale) based on the degradation of rice grains. The highest score was given for the complete degradation of kernels in potassium hydroxide solution and vice versa. The decision-making process is performed visually or manually by trained inspectors, which is important of course, however, time-consuming, laborious, monotonous and of a subjective nature. The increasing demand for objective, consistent and efficient evaluations led to the development of machine vision applications.

This paper proposes an alternative method to supplement the manual decision-making process, by implementing a computerized digital image analysis technique involving the use of a low-cost portable flatbed scanner (commercially known as passport scanner) to objectively measure the rate of dispersion during ASV testing. A new measurement index (Spreading Index) is proposed for calculating the extent of alkali spreading using digital image analysis. The method proposed though approximate is a faster and effective way to determine the ASV.

II. MATERIALS AND METHODS

2.1 Sample collection

In this experiment, a total of 8 varieties of Rice samples, with three different ASV categories (high, intermediate and low) were collected from "Indian Agriculture Research Institute", New Delhi. Five varieties of rice samples with low category, two varieties with intermediate category and one variety with high ASV rating were used for the experiment. Details of rice samples are shown in the Table-2.

Table – 2: Details of Rice sample with ASV rating collected for the experiment

Rice Varieties	ASV Rating	Category
PS 5	6-7	High
PB-1	1-2	Low
PB 1401	1-2	Low
PS-2	1-2	Low
PUSA 1121	3-5	Medium
P 834	1-2	Low
P44	1-2	Low
PS 3	3-5	Medium

2.2 Sample preparation and procedure for manual testing

The entire experiment has been designed with a motivation to reduce the time for analyzing the quality of rice. The conventional method of using KOH to determine ASV (Little et al, 1958) and Bhattacharya and Sowbhagya, 1972), requires a day to analyze a particular rice sample [24-22]. This method is tedious and requires manual intervention as well. In order to determine reference ASV values for this work, the following steps have been followed to perform the alkali testing:

STEP-1: Five whole milled dehusked rice kernels (Fig. 1a) were collected randomly from a 10 gm sample of each variety and placed on a Petri dish so that the grains do not touch each other.

STEP–2: Twenty milliliters of 1.7 % KOH solution was poured in a Petri dish carefully without disturbing the grain positions. The Petri dishes were then covered.

STEP-3: The Petri dishes with rice kernels were kept for 23 hours of incubation at room temperature (25º - 27 ºC).

STEP-4: After 23 hours of incubation, each grain was visually examined for its level of intactness or degree of dispersion (Fig. 1b) and assigned a numerical score (ASV) by 3 human experts as described in Table-I.

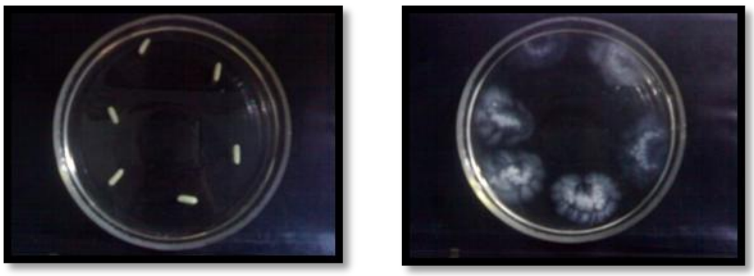


Fig.1a & b: Manual experiment for measurement of ASV (before and after 23 hour of incubation)

STEP- 5: For each sample, the test was repeated 3 times on 5 grains. For the experiments using machine vision, the same procedure was followed as stated above. But, the concentration of the KOH solution was changed from 1.7% to 2.2% in order to reduce the duration of the experiment from 23 hours to 6 hours. However, the experiments were conducted using the KOH solutions with different concentrations ranging from 1.7% to 2.5% and it was observed that the rice grains with high and intermediate value generally dissolve in 6 hours with 2.2%

concentration. Further, it was observed that higher concentration beyond 2.2% dissolved the rice sample to the extent that it was difficult to classify high and intermediate grades of rice grains.

2.3 ASV Testing by Image Analysis

2.3.1 Image capture setup

A customized image capture setup was developed that comprises of a portable flatbed image scanner (Make: Fujitsu, Model: fi-65F). The rice grains were placed in a Petri dish and it was placed on a properly positioned sample holder designed on the scanner. The top cover of the scanner was pasted with black paper, so that, the captured images will appear with a black background. The sample preparation for image analysis was performed following the steps described in 1 and 2. The rice samples were positioned inside the sample holder as shown in Fig. 2.

Fig.2: Imaging Setup for ASV measurement

2.3.2 Image Analysis

The steps of digital image analysis are described below.

2.3.2.1 *Image Capture*:

The color images of the rice samples placed on the Petri dishes were captured for a duration of 6 hours during the incubation period at an interval of 10 minutes. The images were acquired using a flatbed scanner at a resolution of 300 dpi and saved in 24-bit BMP format. A total of 37 images were captured for each sample including one image at the beginning of the experiment.

2.3.2.2 *Image conversion*:

The 24-bit color images were converted to 8-bit grayscale images and then cropping of unwanted portions (outer scanning region beyond Petri dish) of the captured image. Cropped image had an image resolution of 826 × 874 pixels.

2.3.2.3 *Image enhancement*:

Histogram equalization technique was used to process the images to adjust the contrast of the input image by modifying the intensity distribution of the histogram. This gave a linear trend to the cumulative probability function associated with the image. Histogram equalization usually increases the global contrast of the processing image.

2.3.2.4 *Segmentation:*

The outputs of the histogram equalization process were the images of white coloured rice grains with a black background. As the differences between foreground (rice grain) and background objects were very distinct, a global single-valued threshold was used to separate the objects. The search of global threshold value was dynamically conducted using Otsu’s method which searches for a threshold that minimizes the intra-class variances of the segmented image.

2.3.2.5 *Morphological Image analysis:*

Rice kernels (grains) were disintegrated over some time during the experiments. The edges of rice kernels disintegrate more as compared to the middle portions. The binary regions produced by the segmentation process are distorted by noise and texture artifacts. As a result, a few fragmented objects are formed; those are loosely coupled with the boundaries of the rice grains. Dilation, a subclass of morphological image processing, aims to remove these imperfections by accounting for the form and structure of an image. It enlarges an object in an image axially or along transverse direction by controlling the shape referred to as a structuring element, resulting in the recouping of fragmented objects associated with the original rice kernel.

2.3.2.6 *Noise cleaning:*

An area threshold method had been applied to eliminate very small objects with a single pixel or a few pixels area.

2.3.2.7 *Component Labeling:*

Component or particle labeling gives one unique identification number to every particle which makes feature detection easier. Particle labeling had been done using a standard two-pass labeling algorithm. In the first pass, the whole pixel array was scanned. If any unlabeled foreground pixel was found then the top and left neighborhoods of that pixel were checked. If none of them was labeled then the pixel was labeled by the new number. In this way, every pixel was checked with its two neighborhoods and labeled accordingly. After the first pass, the labeled pixel array had some unique labels and some equivalent classes of the same label. In the second pass, those equivalent labels were given new labels which ultimately made the pixel array consisting of each object with different labels.

2.3.2.8 *Particle analysis:*

In this paper, only the area (A) of each rice kernel dipped in the alkali solution had been considered. The calculation of particle area was done by counting the number of pixels within that particle. A new index, S_t (Spreading Index), had been proposed in this paper and described as the ratio of mean area of rice kernels at any point of time (t) and the mean area of rice kernels at the beginning of the test.

$$S_t = \frac{A_t - A_0}{A_0}$$

Where, A_t = mean area of rice kernels at any point of time (t)

A_0 = mean area of rice kernels at the beginning of the test

S_t = Rate of spreading at the time (t)

The spreading of the kernel relative to the initial area was used to eliminate the effect of the kernel dimensional variability. The average area of five rice kernels had been considered to eliminate the uncertainty in chemical reactions between KOH and rice kernels. For each sample, the test was repeated 4 times on 5 grains. The screenshot of the developed software is shown in Fig.3.

Fig.3: Screen shot of the image analysis software

III. RESULT AND DISCUSSION

Prediction of *(S_t)* was performed using models developed following the polynomial regression approach. Firstly, the predictor models had been developed with the help of the datasets in hand and then the test data with few samples been used to predict the approximate *St* for the test dataset. Finally, the ASV rating is assigned based on the maximum *(S_t)* value. Eight different datasets were considered for our experiments. Each dataset consists of two attributes namely the time in a minute and *(S_t)*. Modeling and testing were evaluated using the following two algorithms (Fig.4).

Algorithm 1: Predictor model building

Algorithm steps for predictor model building

Inputs: Data sets (m), Polynomial order (n);
Output: Model Parameters [m×(n+1)];
For each dataset:
Perform polyfit operation;
Store the polynomial coefficients in Model Parameters;
Perform polival operation;
Plot the output values from polyval operation against time
End

Algorithm 2 : Prediction

Algorithm steps for prediction

Inputs: Test dataset, Model Parameters, Time ;
Output: Model_Selected, *St*_max, Time for *St* _max, Error in predicted *St* and time;
For test dataset:
Perform polyval operation using each Model parameters;
Compute and store SSE* in prediction;
Find min SSE;
Select Model;
Compute *St* predictions against Time using selected model;
Select *St*_max and Time for *St* _max;
Compute Error in predicted *St* and time;
End

Fig.4: Algorithms for prediction of ASV

*SSE-Sum of Squared Error

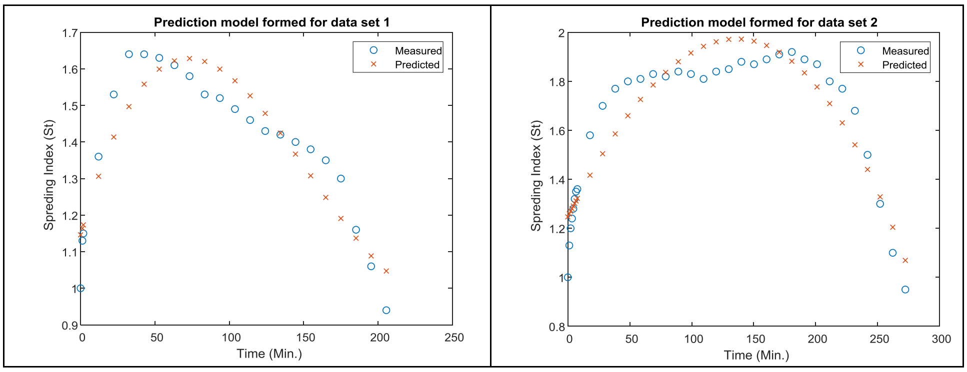
3.1 Data Set Preparation

The experiment was conducted with 8 rice varieties and repeated for 5 times of each sample. Thus the data set formed was forty instances. The data set was divided into two sets viz. 8 datasets (for each variety) was used for model development and 32 datasets were used for testing (each variety repeated for 4 times). Each rice sample data set have two attributes: Time in minute and Spreading Index *(S_t)*.

3.2 Model building using rice data

The rice sample dataset was fed to the predictor model building algorithm (algorithm 1) to develop the prediction models for the rice samples under experiments. The models were implemented based on polynomial fit and the experiments were done for three polynomial orders; 3, 4 and 5. The coefficients of the polynomial functions are the model parameters. In the present experiment, 8 models were formed for eight different varieties of rice samples.

The figures (Fig.5) show the variation of *(S_t)* against time in open circles ('blue' colour) whereas 'x' ('Orange' colour) corresponds to the variation of *(S_t)* following the respective model formed. From all the plots it is clear that the *(S_t)* initially increases and then falls as expected. Due to space restriction, only the plots corresponding to polynomial order 3 have been shown (Fig.5).



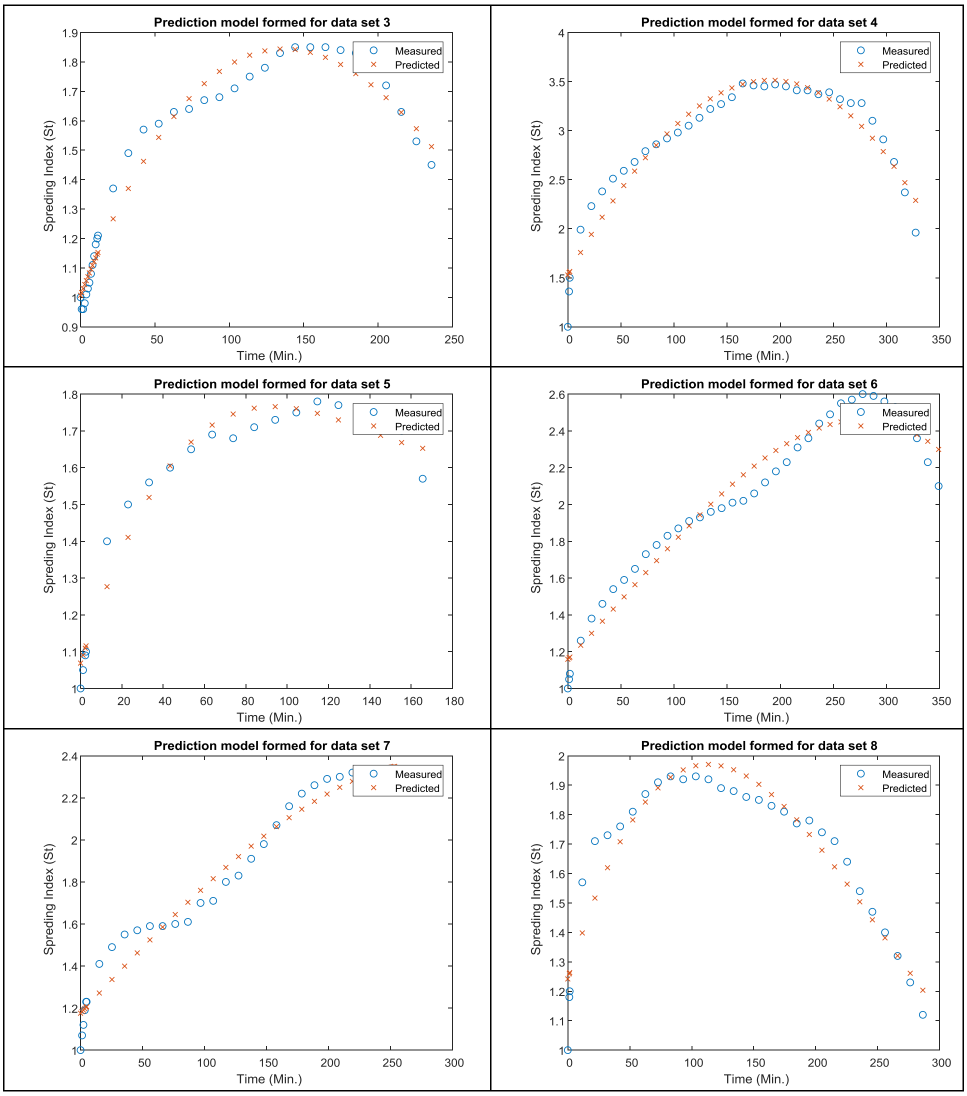


Fig.5: Model formed for 8 varieties of rice samples with polynomial order 3

3.3. Prediction of the Spreading Index (S_t) and ASV

Following the prediction algorithm (algorithm 2), prediction of the *(S_t)* was performed for the rice samples. During this process, only the information of the rice sample for the duration of the first 100 minutes was fed to algorithm 2. The algorithm first determines the best-suited model and then using that model's parameters to predict the maximum *(S_t)* for the rice varieties under test.

3.3.1 Selection of Model

The selection of the best model has been done by finding the minimum SSE (Sum of Squared Error) calculated from the measured and predicted values. The model selection process also considers the time after which the maximum *(S_t)* is obtained for the selected model. In this experiment, polynomials up to fifth-order have been considered, because, higher-order polynomials increases the time of prediction without much improvement in SSE. The results are tabulated as in Table-3. The maximum Spreading Index *(max_S_t)* was obtained as 1.64 at 32.52 minutes for sample (dataset 1) during manual analysis. The predicted values for the same rice verities have been obtained as 1.6284, 1.6490, and 1.6458 at 72, 50 and 44 minutes respectively, using 3^{rd}, 4^{th} and 5^{th} order polynomial.

Table – 3: Experimental results.

Data set No	**Measured**		**Prediction**									
	Max_ S_t	Time_max S_t (Minutes)	Model Select	**Poly. Order 3**		Model Select	**Poly. Order 4**		Model Select	**Poly. Order 5**	
				Max_ S_t	Time		Max_ S_t	Time_M		Max_ S_t	Time_

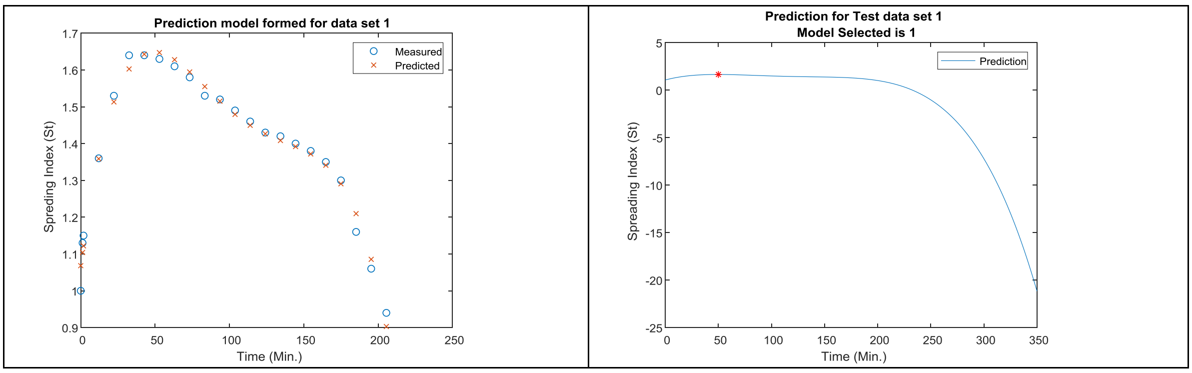
			ed		_Max S_t	ed		ax S_t	ed		Max S_t
1	1.64	32.52	1	1.6284	72	1	1.6490	50	1	1.6458	44
2	1.92	180.72	8	1.9705	114	2	1.8643	84	2	1.8375	60
3	1.85	144.23	3	1.8439	136	3	1.8358	172	3	1.8576	164
4	3.48	164.60	4	3.5131	190	4	3.4657	226	4	3.4993	222
5	1.78	114.60	5	1.7659	94	5	1.7761	132	5	1.7790	124
6	2.6	277.52	5	1.7659	94	6	2.5847	286	6	2.5880	288
7	2.34	250.10	1	1.6284	72	7	2.3880	228	7	2.3118	220
8	1.93	82.92	8	1.9705	114	8	1.9456	88	8	1.9139	76

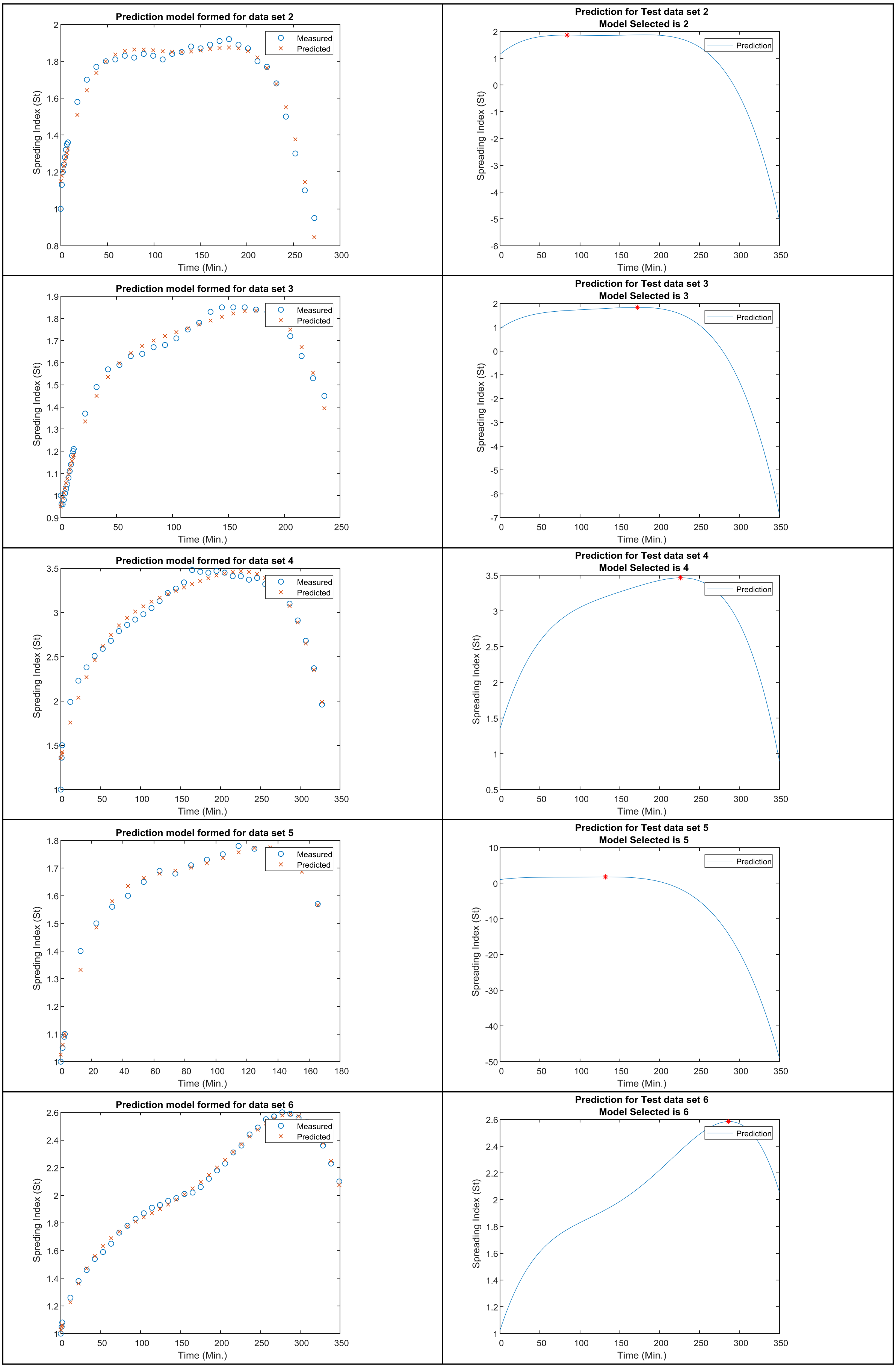
3.3.2 Selection of Polynomial Order

In this experiment, the minimum SSE of S_t and prediction time were selected as the main criteria for the selection of polynomial order. Table-4 shows the error (Error_S_t) calculated from the Table-III and represents the variation between the manual and predicted results. Error_Time represents the variation between the actual time taken to achieve the maximum spread index (measured *Max_S_t*) and the predicted results (predicted *Max_S_t*). The last row of Table-4 shows the corresponding SSE values. It can be observed that both SSE of Error_S_t and Error_Time are minimum for the polynomial of order 4. Also, the samples were tested using higher-order polynomial beyond order 5, but the calculated SSE values were found to increase with higher orders. Therefore, the model parameters corresponding to the polynomial order 4 have been adjudged to be best for the experiments. Fig.6 shows the model build for polynomial order 4 and the prediction curve. The plots for prediction were drawn for a time interval of 2 minutes and a total duration of 350 minutes as shown in the second column. Models having multiple picks, the first pick (represents by a red dot) was considered for the prediction of maximum S_t for the sample.

Table – 4: Computation of sum of squared error (SSE)

Data set No	Poly. Order 3		Poly. Order 4		Poly. Order 5	
	Error_S_t	**Error_Time**	**Error_S_t**	**Error _Time**	**Error_S_t**	**Error _Time**
1	0.0116	-39.48	-0.0090	-17.48	-0.0058	-11.48
2	-0.0505	66.72	0.0557	96.72	0.0825	120.72
3	0.0061	8.23	0.0142	-27.77	-0.0076	-19.77
4	-0.0331	-25.4	0.0143	-61.4	-0.0193	-57.4
5	0.0141	20.6	0.0039	-17.4	0.0010	-9.4
6	0.8341	183.52	0.0153	-8.48	0.0120	-10.48
7	0.7116	178.1	-0.0480	22.1	0.0282	30.1
8	-0.0405	-31.08	-0.0156	-5.08	0.0161	6.92
SSE	**1.20775406**	**73512.6485**	**0.0063863**	**15090.3285**	**0.00847**	**19542.8085**




Prediction model formed for data set 2
Spreading Index (St)
Time (Min.)
Measured
Predicted
Prediction for Test data set 2
Model Selected is 2
Prediction
Prediction model formed for data set 3
Prediction for Test data set 3
Model Selected is 3
Prediction model formed for data set 4
Prediction for Test data set 4
Model Selected is 4
Prediction model formed for data set 5
Prediction for Test data set 5
Model Selected is 5
Prediction model formed for data set 6
Prediction for Test data set 6
Model Selected is 6

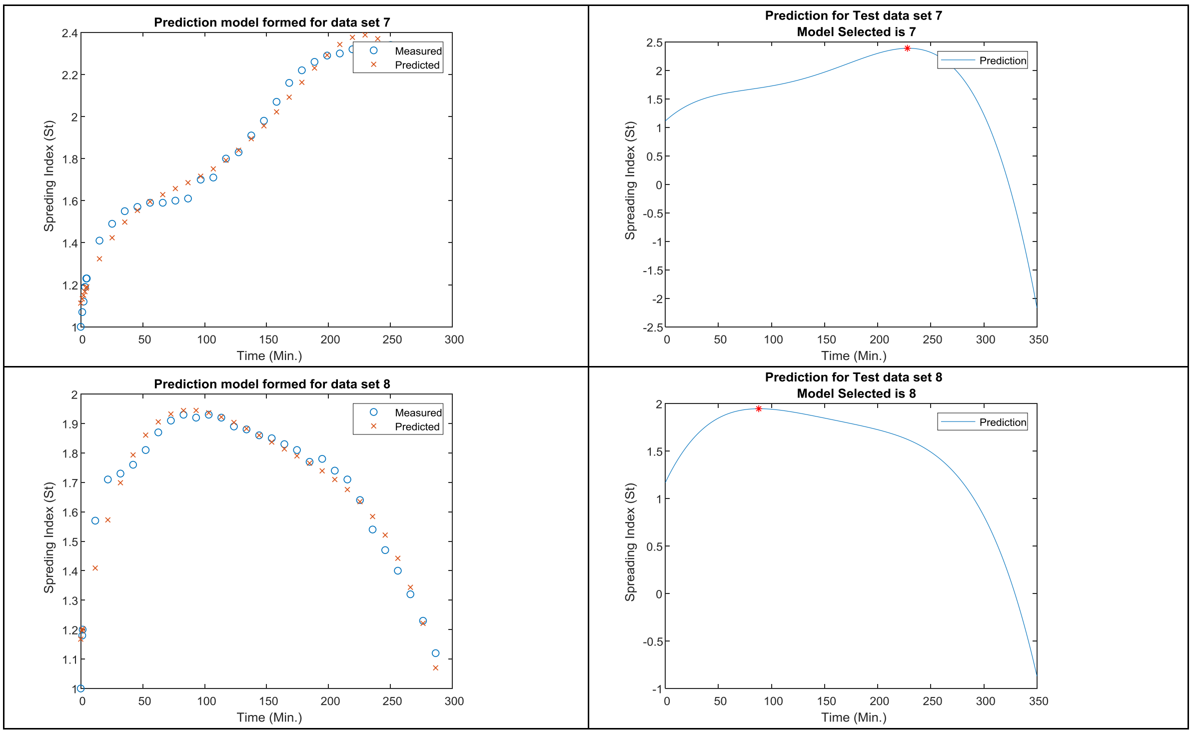


Fig.6: Time vs Spread Index (St) plots using polynomial order 4 for 8 varieties of rice

3.3.3 Prediction of ASV

Prediction of ASV can be obtained by looking at the model selected for a particular rice variety to predict Max_S_t and corresponding time. It is assumed that different varieties of rice sample will be trained prior to testing and development of mathematical model for each rice verities will be pre-requisite for prediction of ASV. Prediction of ASV rating using 4th order polynomial function for eight rice varieties is shown in the Table- 5.

Table – 5: Summary of Results

Data Set	Sample Name	Measured		Predicted		
		ASV Rating	**Actual Max. St**	**Model Selected**	**Predicted Max. St**	**Predicted ASV Rating**
1	PB 1	Low	1.64	1	1.65±0.2	Low
2	PB 1401	Low	1.92	2	1.86±0.1	Low
3	P 834	Low	1.85	3	1.84±0.1	Low
4	PS 5	High	3.48	4	3.47±0.3	High
5	P 44	Low	1.78	5	1.78±0.1	Low
6	PUSA 1121	Medium	2.6	6	2.58±0.2	Medium
7	PS 3	Medium	2.34	7	2.39±0.2	Medium
8	PS 2	Low	1.93	8	1.95±0.2	Low

IV. CONCLUSION

A portable scanner-based machine vision system for the rapid estimation of alkali spreading value (ASV) has been presented in this paper. The image processing technique has been applied to calculate the spreading index which is a measure of the degree of disintegration area during the treatment of rice kernel with KOH solution. The entire experiment is driven towards reducing the time and the manpower required for analyzing the ASV of rice. Through various tests, it is observed that the initial KOH concentration used earlier required a day to perform the quality analysis on a particular rice sample. This method was tedious and required manual intervention as well. Further, the present study proves that the duration of the experiment may be reduced by increasing the concentration from 1.7% (traditionally used) to 2.2%. Thus the result is obtained within a few hours (typically 2 to 3 hours). Though the dataset is collected only for few varieties from one location do not possess wide variability, the solution, however, can be made versatile by building the models of different rice varieties from different geographical regions in India and other rice-producing countries. Nevertheless, the machine vision technique described in this paper being low-cost and portable is affordable by the rice quality control laboratories and has the potential to be a useful measurement tool for ASV.

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