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Effect of Steaming on Accelerated Ageing of Rice (*Oryza sativa* L.)

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A B S T R A C T

Naturally aged rice is generally preferred in Indian subcontinent since, it swells better during cooking, cooked kernels are less sticky with more linear elongation and produces thin gruel. Natural ageing is done by storing harvested paddy for at least 4-6 months before milling. Accelerated ageing is an artificial technique that induces ageing effect in rice within a short period of time. Under hydrothermal treatment, dry (@14% moisture) paddy samples were steamed at three pressures (0.0, 0.5 and 1.0 kg/cm^2 gauge) for 5, 10 and 15 min. The treated paddy samples were milled to study milling, physico-chemical, cooking and textural characteristics of rice. Among all the treatments studied, paddy steaming @ 1.0 kg/cm^2, 5 minwas found to be best for accelerated ageing of rice.

Introduction

Rice (*Oryza sativa* L.) is one of the most important cereals in the world. It is a staple food for more than a half of world's population. About 65% of the population in India consumes rice. India is the second largest producer of rice in the world next to China. In India rice occupies the first place both in area and the production. It covers about 69% of the cultivated area and covers about 63% of the total area under food grain production (FAO, 2008). Commonly, a large amount of the rice is consumed by cooking along with a small portion (around 10%) of processed foods (Le *et al*., 2014).

Cooking quality is one of the most important characters that influence the acceptability of rice. However, the rice from freshly harvested paddy generally leaves a thick gruel texture when being cooked. These cooking properties may not be accustomed to consumers who prefer the fluffiness or firmness of cooked rice. These characteristics of rice could be improved when the freshly rice is traditionally

stored for at least 3-6 months (Indudhara Swamy *et al*., 1978). By natural storage condition, the rice is stored quite a long time, which is considered as a non-economic aspect such as storage space requirement, insect damages and high opening cost. The quality of rice changes during storage. These are basically due to the physicochemical changes occurring in the paddy grains which are affected by the temperature and relative humidity of the environment or the moisture content of the grain.

The process of inducing the changes in rice in a short time to obtain cooking properties, which resemble to that of naturally aged rice, is referred to as accelerated ageing of rice.

Therefore, the present work has been planned to investigate the effect of steaming on accelerated ageing of rice with comparison with that of naturally aged rice.

Materials and Methods

Hydrothermal treatment by dry steaming

Paddy (@ 14 % moisture) was steamed in an Autoclave at 3 different steam pressures of 0, 0.5 and 1.0 kg/cm^2 (gauge pressure) for the durations of 5, 10 and 15 minutes. After steaming, the accumulated moisture in the paddy was removed by sun drying to obtain a final moisture content of about 14 % (w.b.). About 500 g of paddy was used in each trial and each treatment was replicated twice. The dry steaming treatment details are given in Table 1.

Milling of treated paddy samples

The treated paddy samples of various accelerated ageing treatments were de-husked using a laboratory Rubber roll paddy sheller, polished using Abrasive grain polisher and aspirated to remove bran using Aspirator. Then the rice brokens were separated using Rice broken separator.

De-husking of paddy

The treated paddy samples were de-husked using a laboratory Rubber roll paddy sheller. Milling studies of treated paddy samples were conducted by adopting the standard milling test procedure. About 250 g of sample was de-husked in rubber roll sheller in each trial. The clearance between the rubber rolls were pre-adjusted for optimum results. The de-husked product was found to contain a mixture of brown rice (unpolished), little amount of brokens and some unhusked paddy grains. Unhusked paddy was manually separated before polishing.

Polishing brown rice

The brown rice obtained after de-husking paddy sample was polished in an Abrasive grain polisher. The polished grain collected from the polisher was aspirated in a Bran aspirator to separate adhered bran. The brokens in the polished rice was separated by using Rice broken separator and the head rice was collected.

Milling test calculations

The following observations were recorded for calculating the milling characteristics of treated paddy samples:

1. Weight of paddy grain fed to the sheller (kg)
2. Actual weight of paddy shelled (kg)
3. Weight of brown rice (kg)
4. Weight of the milled grains (head rice and brokens) (kg)
5. Weight of the head rice (kg)
6. Weight of the brokens (kg)

The following equations were used for calculating various milling characteristics:

$$\text{Milling yield (\%)} = \left(\frac{\text{Weight of brown rice (kg)} \times \text{Weight of milled rice(kg)}}{\text{Actual weight of paddy (kg)} \times \text{Weight brown rice for polish(kg)}} \right) \times 100$$

$$\text{Head rice yield (\%)} = \frac{\text{Weight of head rice (kg)}}{\text{Weight of milled rice (kg)}} \times 100$$

$$\text{Brokens (\%)} = \frac{\text{Weight of brokens (kg)}}{\text{Weight of milled rice (kg)}} \times 100$$

Determination of physico-chemical and cooking properties of milled rice

Cooking characteristics of polished rice samples were determined by adopting standard procedures. About 5 g of head rice was cooked in 50 ml of boiling distilled water taken in glass beakers that was immersed in boiling water bath. The following properties of cooked rice were then evaluated:

Volumetric expansion ratio

Volume of raw and cooked rice kernels was determined by toluene method (Mohsen in, 1986). Volume of 10 cooked kernels divided by the volume of 10 uncooked kernels gives the volume expansion of the rice sample on cooking. The volumetric expansion ratio was calculated by

$$\text{Volumetric expansion ratio} = \frac{Vc}{Vuc}$$

Where,
Vuc - Volume of uncooked rice kernels, ml
Vc - Volume of cooked rice kernels, ml

Water uptake ratio

Water uptake ratio of cooked rice was calculated by

$$\text{Water uptake ratio} = \frac{Wc - Wuc}{Wuc}$$

Where,
Wuc - Weight of uncooked rice kernels, g
Wc - Weight of cooked rice kernels, g

Elongation ratio

Length of cooked and uncooked kernels was measured by using digital Vernier callipers. Cumulative length of 10 cooked rice kernels divided by the length of 10 uncooked rice kernels were considered to calculate elongation ratio as:

$$\text{Elongation ratio} = \frac{Xc}{Xuc}$$

Where,
Xuc - Average length of 10 uncooked rice kernels, mm
Xc – Average length of 10 cooked rice kernels, mm

Solid loss

After cooking process was completed, the excess water was strained into a pre-weighed petri dish and was kept in hot air oven at 105±1 °C for about 24 h. After all the water was evaporated the petri dish with the sample was then cooled in a desiccator and weighed. An increase in weight of the petri dish (i.e. weight of solids leached) divided by the weight of the rice sample taken is then defined as the solid loss.

$$\text{Solids loss (\%)} = \left(\frac{\text{Weight of solids leached}}{\text{Weight of rice sample taken}} \right) \times 100$$

Cooking time

After 10 min of cooking one rice kernel was taken out after every 30 s from the beaker and pressed between two microscope glass slides. The appearance of a chalky core indicated uncooked sample. The time (minutes) at which rice showed no chalky core was reported as cooking time.

Whiteness index

Whiteness index of cooked rice gives a measure which correlates the visual ratings of whiteness for certain white and near white surfaces. The measurement is based on the CIE-LAB colour system using tristimulus colour values of L^*, a^* and b^*. The colour of cooked rice samples was measured by using Spectrophotometer CM-5. The whiteness index was then determined (Saricoban and Yilmaz, 2010).

$$\text{Whiteness index} = 100 - \sqrt{(100 - L^*)^2 + (a^*)^2 + (b^*)^2}$$

Where,
L* - Lightness value
a* - Redness /Greeness value
b* - Yellowness / Blueness value

Gel consistency

Materials and Methods

95 % Ethanol
0.025 % thymol blue
0.2N KOH
13 x 100 mm culture tubes
Water bath
Ice cold water
Graph paper

Composition of reaction mixtures

A. 0.2N KOH solution
Dissolve 1.12g KOH in 100ml of distilled water

Procedure

- Place 100 mg rice powder (12 % moisture) in 13 x 100 mm culture tubes
- Wet the powder with 0.2 ml 95 % ethanol containing 0.025 % thymol blue.
- Shake the tube and add 2.0 ml of 0.2N KOH immediately and disperse the mixture.
- Cover the tubes with glass marbles and place for 8 minutes in a boiling water bath.
- Remove the samples, keep at room temperature for 5 min, and then cool in ice cold water for 15 minutes.
- Lay tubes horizontally over a ruled paper graduated in millimetres and measure the length of the gel from the bottom of the test tube after 30 - 60 minutes.

The gel consistency is classified as given below.

Gel consistency

Category	Gel length, mm
Soft	61-100
Medium	41-60
Medium hard	36-40
Hard	26-35

Textural properties of cooked rice

Texture is one of the most important quality attributes affecting the acceptability of food products. Textural properties were determined using Texture Analyser. As per the recommendation of equipment manufacturer, Texture Profile Analysis (TPA) test (compressive) was conducted for cooked rice. Three cooked kernels were placed on the base platform of Texture Analyser. A cylindrical plunger of 25 mm diameter attached to a 100 kg load cell was used for the TPA test. The TPA curve (Fig. 1) was drawn from the force versus time data (Gujral *et al*., 2002) using the Texture Expert software provided. Texture Analyser settings are given in Table 2. Various textural characteristics of cooked rice kernels were deduced from the TPA curve and are given below. The values reported were the mean of three replications.

Hardness

Hardness of cooked rice is the peak force (N) of first compression (1f) in the TPA curve.

Stickiness

Stickiness of cooked rice is the peak force (N) below the zero force i.e, negative force (3f) in the TPA curve.

Cohesiveness

Cohesiveness was computed from the TPA curve as,

Cohesiveness = A_2 / A_1

Where,
A_1 - Area of TPA curve under first compression
A_2 - Area of TPA curve under second compression.

Adhesiveness

Adhesiveness (N.s) of cooked rice is the area under the curve due to adhesion i.e, negative area (A_3)

Results and Discussion

Characteristics of freshly harvested and naturally aged paddy

The milling characteristics of paddy, both freshly harvested and naturally aged (for 6 months), and the physico-chemical and textural properties of their cooked rice samples are presented in Table 3. Though the milling yield was almost same for fresh and aged paddy, the head yield was considerably higher with naturally aged paddy (98.27 %) when compared to fresh paddy (93.11 %). Consequently the breakage of rice was obviously lower with aged paddy. When the physico-chemical characteristics of cooked rice was considered, it could be seen that the volumetric expansion ratio (2.60), water uptake ratio (3.05), elongation ratio (1.56) and cooking time (25 min) were markedly higher; and solid loss (4.23 %) and gel consistency (28.50 mm) were desirably lower, in case of rice from aged paddy when compared to fresh paddy. Further, the stickiness and adhesiveness of cooked kernels of aged paddy were observed to be less.

Paddy (@ 14 % moisture content) was steamed in an autoclave at three steam pressures for three different durations and the treated paddy was milled and the milling characteristics were determined.

Milling characteristics

The results of milling trails of different paddy samples which were treated by using autoclave (dry steaming), are presented in Figure 2.

Milling yield

Figure 2 shows the effect of dry steaming of paddy (14 % initial moisture content) at different steam pressures on the milling yield. It was found that for the dry steamed paddy samples, the milling yield varied from 79.24-76.66 %. The maximum value of milling yield of 79.24 % observed at steam pressure (gauge pressure) of 1.0 kg/cm^2 and for the steaming duration of 5 min and the minimum value of milling yield was 76.66 % observed at steam pressure of 0.0 kg/cm^2 for 5 minutes of steaming.

Head yield

Figure 2 shows the effect of dry steaming of paddy (14 % initial moisture content) on the head yield (%). The maximum head yield (98.44 %) was observed with paddy steamed

at 1.0 kg/cm^2 for 10 min and the minimum value of head yield (96.53 %) was recorded with paddy steamed at steam pressure of 0.0 kg/cm^2 for 5 minutes.

Breakage

The effect of dry steaming of paddy (14 % initial moisture content) on the rice breakage is shown in Figure 2. The maximum value of breakage was usually observed at minimum value of head yield and vice versa. The maximum and minimum rice breakage recorded were 3.47 and 1.56 % observed with paddy samples steamed at 0.0 kg/cm^2 for 5 minutes and 1.0 kg/cm^2 for 10 minutes, respectively.

Physico-chemical and cooking properties of milled rice

Physico-chemical and cooking properties of polished rice of dry steamed paddy samples were determined by adopting standard procedures. The following properties of cooked rice are presented below.

Volumetric expansion ratio

Table 4 shows the effect of dry steaming of paddy at different steam pressures on the volumetric expansion ratio of cooked rice. The mean volumetric expansion ratio of rice obtained from paddy steamed at different steam pressures (gauge) 0.0, 0.5 and 1.0 kg/cm^2 was 2.60, 2.6067 and 2.414, respectively; and the above values for different steaming times of 5, 10 and 15 min were 2.64, 2.58 and 2.401, respectively.

The volumetric expansion ratio increased from 2.27 for fresh rice to 2.6 recorded with rice obtained from naturally aged paddy at room temperature for six months. The volumetric expansion ratio of rice obtained from dry steamed paddy was not significant with respect to both steam pressure as well as steaming time.

For aged paddy samples the volumetric expansion ratio was found to be more as compared to the freshly harvested paddy. Of all the dry steamed samples, the maximum volumetric expansion ratio was 2.73, observed at 0.0 and 1.0 kg/cm^2 of steam pressure for 5 min of steaming time.

Water uptake ratio

Effect of dry steaming of paddy at different steam pressures on the water uptake ratio of cooked rice is presented in Table 5. The mean water uptake ratio of rice obtained from paddy steamed at different steam pressures (gauge) of 0.0, 0.5 and 1.0 kg/cm^2 was 1.9870, 2.1115 and 2.2785, respectively; and the above values for different steaming times of 5, 10 and 15 min were 2.0098, 2.1128 and 2.2543, respectively.

The water uptake ratio for fresh rice was 2.55 which increased to 3.05 for rice of six months naturally aged paddy at room temperature (Table 3). The water uptake ratio of dry steamed sample was not significant with respect to both steam pressure as well as steaming time.

For aged paddy samples the water uptake ratio of rice was found to be more compared to freshly harvested paddy. Among all the dry steamed samples, the maximum water uptake ratio was 2.378, observed for paddy steamed at 0.5 kg/cm^2 of steam pressure for 10 min.

Elongation ratio

Table 6 shows the effect of dry steaming of paddy at different steam pressures on the elongation ratio of cooked rice. The mean elongation ratio of sample treated using autoclave (dry steaming) at 14 % (w.b.) of

paddy moisture content at different steam pressures (gauge) of 0.0, 0.5 and 1.0 kg/cm^2 was 1.4795, 1.4868 and 1.4828, respectively; and the same value for different steaming times of 5, 10 and 15 min was 1.4845, 1.467 and 1.4977, respectively.

From the Table 3, shows the elongation ratio of rice from freshly harvested paddy was 1.45 and that of from naturally aged paddy, it was 1.56 which showed that elongation ratio of rice increased on ageing. The elongation ratio of rice of dry steamed paddy sample was not significant with respect to the both steam pressure and steaming time. Of all the dry steamed paddy samples, the maximum elongation ratio of rice was 1.5430, observed in paddy steamed at 0.5 kg/cm^2 of steam pressure for 5 min.

Solid loss (%)

The effect of dry steaming of paddy at different steam pressures on the solid loss of cooked rice is shown in Table 7. The mean solid loss during cooking of rice from paddy samples treated using autoclave (dry steaming) at different steam pressures 0.0, 0.5 and 1.0 kg/cm^2 was 3.7047, 3.4173 and 2.529 %, respectively; and the above values for different steaming times of 5, 10 and 15 min were 3.2433, 3.265 and 3.1427 %, respectively (Table 3).

The solid loss of rice from freshly harvested paddy was 4.37 % and that of naturally aged paddy it was 4.23 %, which indicated that the leaching of solids during cooking will be reduced on ageing. The solid loss of rice from dry steamed paddy sample was significant with respect to the steam pressure. Among all the dry steamed samples the minimum solid loss was 2.51 % in the rice obtained from paddy steamed at 1.0 kg/cm^2 of steam pressure for 5 min.

Cooking time (min)

Table 8 shows the effect of dry steaming of paddy at different steam pressure on the cooking time of rice. The mean cooking time of rice from paddy samples treated using autoclave (dry steaming) at different steam pressures of 0.0, 0.5 and 1.0 kg/cm^2 was 21.50, 21.167 and 22.167 min, respectively; and the above values for different steaming times of 5, 10 and 15 min were 23.33, 21.167 and 20.33 min, respectively.

From the Table 3, it was found that the cooking time of rice from fresh and naturally aged paddy was 21 and 25 min, respectively. The cooking time of rice from dry steamed paddy samples was significant with respect to steaming time.

The cooking time of rice obtained from aged paddy samples was found to be more compared to rice from freshly harvested paddy. Among all the dry steamed paddy samples the minimum cooking time was 19 min observed for paddy steamed at 0.0 kg/cm^2 of steam pressure for 15 min.

Whiteness index

Table 9 shows the effect of dry steaming of paddy at different steam pressures on the whiteness index of cooked rice. The mean whiteness index of rice from paddy dry steamed at different steam of 0.0, 0.5 and 1.0 kg/cm^2 was respectively, 72.5703, 71.5712 and 69.7738; and the above values for different steaming times of 5, 10 and 15 minutes were 71.6177, 71.5242 and 70.7735, respectively.

The whiteness index of cooked rice slightly decreased from 72.47 to 71.01 when at room temperature paddy was naturally aged for six months (Table 3). The variations in whiteness index of rice from dry steamed paddy samples

were highly significant with respect to steam pressure.

For aged samples, the whiteness index was found to be less compared to rice of freshly harvested paddy. Of all the dry steamed samples the maximum whiteness index of rice was 73.019 observed for paddy steamed at 0.0 kg/cm^2 of steam pressure for 10 min.

Gel consistency

The effect of dry steaming of paddy at different steam pressures on the gel consistency of cooked rice is presented in Table 10. The mean gel consistency of rice from paddy samples treated using autoclave at different steam pressures of 0.0, 0.5 and 1.0 kg/cm^2 were 30.33, 30.5 and 30.5, respectively; and the above values for different steaming times of 5, 10 and 15 minutes were 29.83, 31 and 30.5, respectively.

From the Table 3 it was found that the gel consistency of fresh and naturally aged paddy was 32 and 28.5, respectively. For aged samples the gel consistency of rice was found to be less compared to rice of freshly harvested paddy.

The gel consistency of rice from dry steamed paddy sample was not significant with respect to steam pressure as well as steaming time. Of all the dry steamed samples the minimum gel consistency was 29, observed for paddy steamed at 0.5 kg/cm^2 of steam pressure for 5 min.

Textural properties of cooked rice

Various textural characteristics of cooked rice kernels were deduced from the Texture Profile Analysis curves obtained from Texture Analyser. The values reported were the mean of three replications.

Hardness

Table 11 shows the effect of dry steaming of paddy on the hardness of cooked rice. The mean hardness value of cooked rice kernel obtained from dry steamed at different steam pressures 0.0, 0.5 and 1.0 kg/cm^2 were 11.7489, 12.1437 and 12.8389 N, respectively; and the same values for different steaming times of 5, 10 and 15 min were 11.7161, 12.8803 and 12.135 N, respectively. The hardness values cooked rice kernels of fresh and naturally aged paddy were 3.5765 and 4.9342 N, respectively (Table 3). Generally, the hardness of the cooked rice grain increased on ageing.

Stickiness

The effect of dry steaming of paddy on the stickiness of cooked rice is presented in Table 12. The mean stickiness value of sample treated using autoclave (dry steaming) at different steam pressures of 0.0, 0.5 and 1.0 kg/cm^2 were -0.0656, -0.1386 and -0.0517 N, respectively; and the above values for different steaming times of 5, 10 and 15 minutes were -0.0683, -0.0962 and -0.0913 N, respectively. The stickiness of cooked rice kernels of fresh and naturally aged paddy were -0.4913 and -0.2598 N, respectively (Table 3). In general, the stickiness of the cooked rice decreased on ageing.

Cohesiveness

The effect of dry steaming of paddy on the cohesiveness of cooked rice kernels is presented in Table 13. The mean cohesiveness value of cooked rice kernels from dry steam treated paddy samples at different steam pressures of 0.0, 0.5 and 1.0 kg/cm^2 were 0.1552, 0.1409 and 0.1548, respectively; and the cohesiveness values for different steaming times of 5, 10 and 15 min were 0.1342, 0.1565 and 0.1602, respectively. It could be

observed in Table 3, that the cohesiveness of cooked rice kernels of fresh and naturally aged paddy was 0.1082 and 0.1479, respectively.

Adhesiveness

The effect of dry steaming of paddy on the adhesiveness of cooked rice is presented in Table 14. The mean stickiness value of cooked rice kernels from paddy samples treated using autoclave (dry steaming) at different steam pressures of 0.0, 0.5 and 1.0 kg/cm^2 were -0.0522, -0.099 and -0.1639 N.s, respectively; and the above values for different steaming times of 5, 10 and 15 min were -0.1811, -0.0677 and -0.0663 N.s, respectively. The adhesiveness of cooked rice of fresh and naturally aged paddy (6 months) was -0.1587 and -0.1116 N.s (Table 3).

Table.1 Hydrothermal treatment of paddy by dry steaming

Steam Pressure (kg/cm^2, gauge)	Steaming Time (min)
0	5
	10
	15
0.5	5
	10
	15
1.0	5
	10
	15

Table.2 Texture analyser settings for texture profile analysis of cooked rice

TA Settings	
Mode	Measure force in compression
Option	Cycle until count
Data acquisition rate	400 pps
Pre-test speed	0.5 mm/s
Test speed	0.5 mm/s
Post-test speed	10 mm/s
Distance	70 %
Count	2
Load Cell	100 kg
Temperature	25 °C
Trigger type	Auto
Force	0.1 N
Force	N
Distance	% strain
Stop plot at final	

Table.3 Milling characteristics of freshly harvested and naturally aged paddy and physico-chemical and textural properties of their cooked rice

Property	Freshly Harvested Paddy	Naturally Aged paddy
Milling characteristics of paddy		
Milling Yield (%)	77.61	77.00
Head Yield (%)	93.11	98.27
Breakage (%)	6.89	1.73
Physico-chemical properties of cooked rice		
Volume Expansion Ratio	2.27	2.60
Water Uptake Ratio	2.55	3.05
Elongation Ratio	1.45	1.56
Solid Loss (%)	4.37	4.23
Cooking Time (min)	21.00	25.00
Whiteness Index	72.47	71.01
Gel Consistency (mm)	32.00	28.50
Textural properties of cooked rice		
Hardness (N)	3.5765	4.9342
Stickiness (N)	-0.4913	-0.2598
Cohesiveness	0.1082	0.1479
Adhesiveness (N.s)	-0.1587	-0.1116

Table.4 Effect of dry steaming of paddy at different steam pressures on volumetric expansion ratio of cooked rice

Steam Pressure (P) (kg/cm^2 - gauge)	Volumetric Expansion Ratio			
	Steaming Time (S)			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	2.7300	2.6100	2.4600	2.6000
P_2(0.5)	2.7300	2.5600	2.5300	2.6067
P_3(1.0)	2.4600	2.5700	2.2130	2.4143
Mean	2.6400	2.5800	2.4010	**2.5403**

ANOVA			
	F-value	SE_m	CD @ 1 %
P	NS	0.0747	-
S	NS	0.0747	-
P x S	NS	0.1294	-

Note: ** - Highly significant NS - Non significant

Table.5 Effect of dry steaming of paddy at different steam pressures on water uptake ratio of cooked rice

Steam Pressure (P) (kg/cm^2 - gauge)	Elongation Ratio			
	Steaming Time (S)			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	1.4390	1.4650	1.5345	1.4795
P_2(0.5)	1.5430	1.4580	1.4595	1.4868
P_3(1.0)	1.4715	1.4780	1.4990	1.4828
Mean	1.4845	1.4670	1.4977	**1.4831**

ANOVA			
	F-value	SE_m	CD @ 1 %
P	NS	0.0928	-
S	NS	0.0928	-
P x S	NS	0.1607	-

Note: ** - Highly significant NS - Non significant

Table.6 Effect of dry steaming of paddy at different steam pressures on elongation ratio of cooked rice

Steam Pressure (P) (kg/cm^2 - gauge)	Solid Loss (%)			
	Steaming Time (S)			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	3.7710	3.8040	3.5390	3.7047
P_2(0.5)	3.4490	3.4220	3.3810	3.4173
P_3(1.0)	2.5100	2.5690	2.5080	2.5290
Mean	3.2433	3.2650	3.1427	**3.2170**

ANOVA			
	F-value	SE_m	CD @ 1 %
P	NS	0.0055	-
S	NS	0.0055	-
P x S	**	0.0095	0.0438

Note: ** - Highly significant NS - Non significant

Table.7 Effect of dry steaming of paddy at different steam pressures on solid loss of cooked rice

Steam Pressure (P) (kg/cm^2 - gauge)	Cooking Time (min)			
	Steaming Time (S)			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	24.00	21.50	19.00	21.50
P_2(0.5)	22.50	20.00	21.00	21.1667
P_3(1.0)	23.50	22.00	21.00	22.1667
Mean	23.3333	21.1667	20.3333	**21.6111**

ANOVA			
	F-value	SE_m	CD @ 1 %
P	**	0.0553	0.2541
S	NS	0.0553	-
P x S	NS	0.0958	-

Note: ** - Highly significant NS - Non significant

Table.8 Effect of dry steaming of paddy at different steam pressure on the cooking time of cooked rice

Steam Pressure (kg/cm^2 - gauge)	Whiteness Index			
	Steaming Time			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	73.011	73.019	71.682	72.5703
P_2(0.5)	71.637	71.815	71.262	71.5712
P_3(1.0)	70.206	69.739	69.378	69.7738
Mean	71.6177	71.5242	70.7735	**71.3051**

ANOVA			
	F-value	SE_m	CD @ 1 %
P	NS	0.5000	-
S	**	0.5000	2.2977
P x S	NS	0.8660	-

Note: ** - Highly significant NS - Non significant

Table.9 Effect of dry steaming of paddy at different steam pressures on whiteness index of cooked rice

Steam Pressure (kg/cm^2 - gauge)	Whiteness Index			
	Steaming Time			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	73.011	73.019	71.682	72.5703
P_2(0.5)	71.637	71.815	71.262	71.5712
P_3(1.0)	70.206	69.739	69.378	69.7738
Mean	71.6177	71.5242	70.7735	**71.3051**

ANOVA			
	F-value	**SE_m**	**CD @ 1 %**
P	**	0.3527	1.6210
S	NS	0.3527	-
P x S	NS	0.6110	-

Note: ** - Highly significant NS - Non significant

Table.10 Effect of dry steaming of paddy at different steam pressures on gel consistency of cooked rice

Steam Pressure (P) (kg/cm^2 - gauge)	Gel Consistency			
	Steaming Time (S)			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	31.00	29.50	30.50	30.3333
P_2(0.5)	29.00	32.00	30.50	30.5000
P_3(1.0)	29.50	31.50	30.50	30.5000
Mean	29.833	31.0000	30.5000	**30.4444**

ANOVA			
	F-value	**SE_m**	**CD @ 1 %**
P	NS	0.5358	-
S	NS	0.5358	-
P x S	NS	0.9280	-

Note: ** - Highly significant NS - Non significant

Table.11 Effect of dry steaming of paddy on the hardness of cooked rice

Steam Pressure (P) (kg/cm^2 - gauge)	Hardness (N)			
	Steaming Time (S)			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	10.975	11.6217	12.65	11.7489
P_2(0.5)	12.5183	12.501	11.4118	12.1437
P_3(1.0)	11.655	14.5183	12.3433	12.8389
Mean	11.7161	12.8803	12.135	**12.2438**

Table.12 Effect of dry steaming of paddy on the stickiness of cooked rice

Steam Pressure (P) (kg/cm^2 - gauge)	Stickiness (N)			
	Steaming Time (S)			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	-0.0617	-0.0683	-0.0667	-0.0656
P_2(0.5)	-0.0733	-0.1853	-0.1572	-0.1386
P_3(1.0)	-0.07	-0.035	-0.05	-0.0517
Mean	-0.0683	-0.0962	-0.0913	**-0.0853**

Table.13 Effect of dry steaming of paddy on the cohesiveness of cooked rice

Steam Pressure (P) (kg/cm^2 - gauge)	Cohesiveness			
	Steaming Time (S)			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	0.1498	0.1621	0.1538	0.1552
P_2(0.5)	0.1245	0.148	0.1502	0.1409
P_3(1.0)	0.1285	0.1595	0.1766	0.1548
Mean	0.1342	0.1565	0.1602	**0.1503**

Table.14 Effect of dry steaming of paddy on the adhesiveness of cooked rice

Steam Pressure (P) (kg/cm^2 - gauge)	Adhesiveness (N.s)			
	Steaming Time (S)			Mean
	S_1 (5 min)	S_2 (10 min)	S_3 (15 min)	
P_1(0.0)	-0.0467	-0.0517	-0.0583	-0.0522
P_2(0.5)	-0.0967	-0.1164	-0.0839	-0.099
P_3(1.0)	-0.4	-0.035	-0.0567	-0.1639
Mean	-0.1811	-0.0677	-0.0663	**-0.105**

Fig.1 Texture Profile Analysis (TPA) of cooked rice

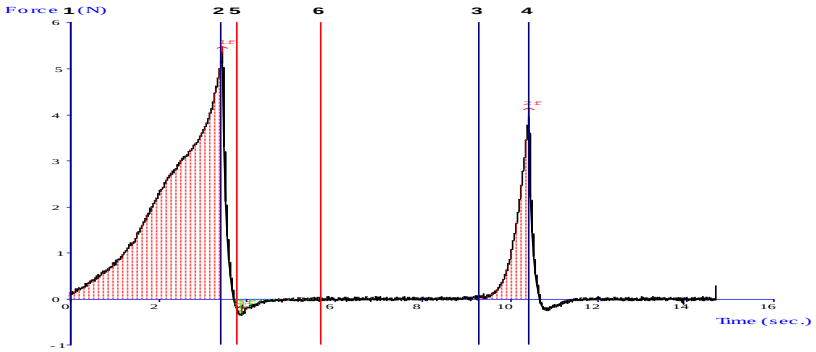
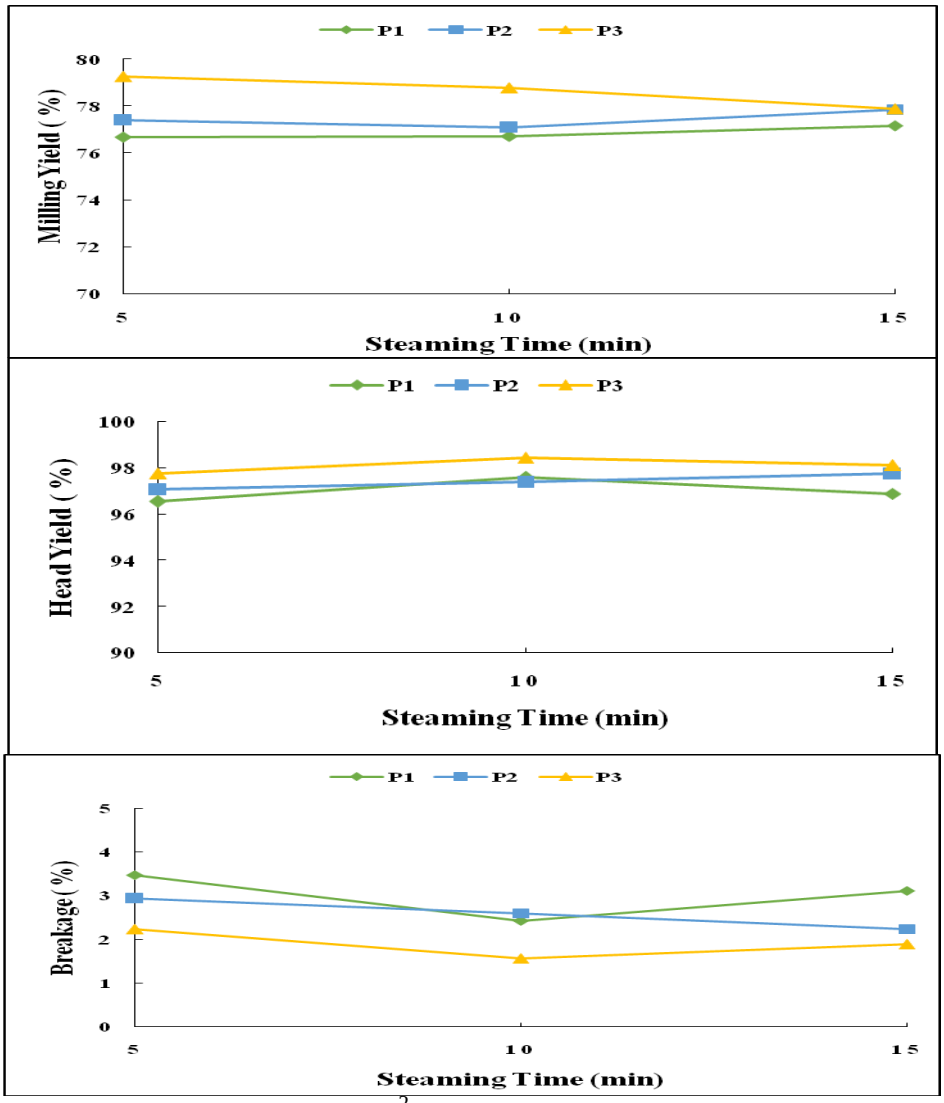


Fig.2 Effect of dry steaming of paddy at different steam pressures on the milling yield, head yield and breakage



P_1 - 0.0, P_2 - 0.5, P_3 -1.0 kg/cm^2

Paddy (@ 14 % moisture content) was steamed in an autoclave at three steam pressures for three different durations and the treated paddy was milled and the results of milling characteristics are discussed below.

Milling characteristics

The maximum value of milling yield of 79.24 % observed at steam pressure (gauge pressure) of 1.0 kg/cm^2 and for the steaming duration of 5 min. The maximum head yield (98.44 %) was observed with paddy steamed at 1.0 kg/cm^2 for 10 min. The minimum value of rice breakage recorded was 1.56 % observed with paddy samples steamed at 1.0 kg/cm^2 for 10 minutes.

Generally, hydrothermal treatment improved the milling yield, head yield and the broken rice percentage however decreased. The main reason for improvement in milling characteristics of rice was that during steaming, the outer layer got loosened from the caryopsis.

After drying, these treated grains had loosely attached outer husk layer which could be easily dehulled by the machine.

Further, the hydrothermal treatment hardened the endosperm due to gelatinization of starch and subsequent retro gradation.

This resulted in improvement of head yield and reduced the rice breakage during milling (Ali and Bhattacharya, 1980; Mecham *et al*., 1961).

Physico-chemical and cooking properties of milled rice

Physico-chemical and cooking properties of polished rice of dry steamed paddy samples were determined and the results are discussed below.

Volumetric expansion ratio

Of all the dry steamed samples, the maximum volumetric expansion ratio was 2.73, observed at 0.0 and 1.0 kg/cm^2 of steam pressure for 5 min of steaming time given in Table 4. The volumetric expansion ratio of rice obtained from dry steamed paddy was not significant with respect to both steam pressure as well as steaming time.

Water uptake ratio

Among all the dry steamed samples, the maximum water uptake ratio was 2.378, observed for paddy steamed at 0.5 kg/cm^2 of steam pressure for 10 min (Table 5). The water uptake ratio was not significant with the dry steaming technique.

Elongation ratio

Table 6 shows the effect of dry steaming of paddy at different steam pressures on the elongation ratio of cooked rice. Of all the dry steamed paddy samples, the maximum elongation ratio of rice was 1.5430, observed in paddy steamed at 0.5 kg/cm^2 of steam pressure for 5 min. The elongation ratio was not significant with respect to steaming pressure as well as steaming time.

Solid loss

Among all the dry steamed samples the minimum solid loss was 2.51 % in the rice obtained from paddy steamed at 1.0 kg/cm^2 of steam pressure for 5 min (Table 7). There was a drastic decrease in the solid loss compared to other two techniques. Aged rice grains were more resistant to disintegration during grain swelling leading to the reduced solid loss. Pastiness has been shown to be due to disintegration of fresh rice leading to dispersion of the starch granules in the cooking water and the formation of a viscous

sticky gruel (Desikachar and Subrahmanyan, 1959).

Cooking time

Among all the dry steamed paddy samples the minimum cooking time was 19 min observed for paddy steamed at 0.0 kg/cm^2 of steam pressure for 15 min given in Table 8.

The cooking time of accelerated aged paddy was more compared to fresh paddy and the reason for the increase in cooking time may be due to the increase in water insolubility of rice starch during steaming.

The increase in water insolubility of rice starch has taken place during the ageing process resulting in slower rate of cooking (Rosniyana *et al*., 2004). The steaming time of dry steaming process has significant effect on the cooking time.

Whiteness index

Table 9 shows the effect of dry steaming of paddy at different steam pressures on the whiteness index of cooked rice. Of all the dry steamed samples the maximum whiteness index of rice was 73.019 observed for paddy steamed at 0.0 kg/cm^2 of steam pressure for 10 min which was more compared to fresh and aged paddy (Table 3). The results showed that dry steaming enhances the whiteness of the cooked rice as compared to naturally aged rice. The steam pressure of dry steaming technique showed significant effect on the whiteness index.

Gel consistency

Of all the dry steamed samples the minimum gel consistency was 29, observed for paddy steamed at 0.5 kg/cm^2 of steam pressure for 5 min given in Table 10.

Gel consistency values were not significant with respect to both steam pressure as well as steaming time.

Textural properties of cooked rice

Accelerated ageing lead to an increase in the hardness of rice. This may be attributed to the filling up of air spaces and fissures in the rice due to starch gelatinization. Hardness increased with increasing moisture content due to increased starch gelatinization (Gujral and Kumar, 2003). Cohesiveness is the extent to which a sample tends to retain its shape (texture) after compression.

The increased gelatinization of the starch may be responsible in increasing the cohesiveness. Cooked aged rice was harder and less sticky than cooked freshly harvested rice, as measured by texturometer (Okabe, 1979). Short-time steaming of rough rice was also effective in reducing the stickiness of cooked, treated and milled rice (Fellers and Deissinger, 1983).

Based on the results obtained in this study, the following important conclusions could be drawn.

From 9 dry steam treated paddy samples the maximum milling was 79.24 % (steaming @ 1.0 kg/cm^2, 5 min); maximum head yield was 98.44 % (steaming @ 1.0 kg/cm^2, 10 min); maximum volumetric expansion ratio of cooked rice was 2.73 (steaming @ 0.0 / 1.0 kg/cm^2, 5 min); maximum water uptake ratio was 2.378 (steaming @ 0.5 kg/cm^2, 10 min); maximum elongation ratio was 1.543 (steaming @ 0.5 kg/cm^2, 5 min); minimum solid loss during cooking was 2.51 % (steaming @ 1.0 kg/cm^2, 5 min); minimum cooking time was 19 min (steaming @ 0.0 kg/cm^2, 15 min); and maximum whiteness index was 73.019 (steaming @ 0.0 kg/cm^2, 10 min).

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