CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: **http://chimie-biologie.ubm.ro/carpathian_journal/index.html**

EFFECT OF HYDROTHERMAL TREATMENTS ON PASTING PROPERTIES OF PARBOILED BROWN RICE

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https://doi.org/10.34302/crpjfst/2021.13.3.3

Article history:
Received:
22 October 2020
Accepted:
5 July 2021

Keywords:
Brown rice;
Packaging;
Quality;
Soaking;
Steaming;
Shelf life.

ABSTRACT

The rice varieties namely *PR-115*, *PR-118* and *Punjab mehak* were subjected to three different treatments to improve quality and shelf life of brown rice. Paddy was milled to brown rice and stored at room temperature in four different types of packaging materials. Brown rice was assessed periodically for changes in pasting qualities. Milling quality improved with treatments. Pasting quality improved with treatments leaving better quality brown rice. Hot water treatment followed by steaming for 15 min was found to be best among all treatments. Peak viscosity varied significantly as influenced by variety, treatment, and storage. Peak viscosity decreased with storage. Peak viscosity decreased with treatments. Packaging material showed non-significant effect on peak viscosity. *Punjab mehak* had higher hold viscosity followed by *PR-118*and *PR-115* in the order. Breakdown viscosity varied significantly with respect to all factors except packaging material. Breakdown values decreased with storage period. Setback viscosity followed reverse pattern as that for breakdown viscosity. Setback viscosity decreased with treatments and increased with storage period. Low setback viscosity values of hydrothermally treated flour samples indicated lesser tendency to retrograde or syneresis upon cooling. Packaging in plastic bag under vacuum was found to be the best packaging material for control however for treated samples experimental data showed that packaging material play no significant role. Overall treatments proved to be functional in improving quality and shelf life of brown rice.

1. Introduction

Hydrothermal treatments altered the pasting and gelling properties of rice starch, resulting in lower peak viscosity heights, lower setbacks and greater swelling consistency as investigated by Shih *et al.* (2007). The modified starch showed increased gelatinization temperature and narrower gelatinization temperature ranges on ANN (annealed) or broader ones on HMT (heat-moisture treatment). The effect was more pronounced for HMT than for ANN.

The investigation that with drying process (high-temperature fluidized bed drying, tempering and ventilation) starch granules lost their polygonal shape as revealed by scanning electron microscopy and gelatinization of rice starch had partially taken place was undertaken by Jaisut *et al.* (2008). DSC thermogram showed the amylase lipid complex formation for the treated brown rice, resulting in lowering starch hydrolysis. The head rice yield of the treated samples was slightly lower than that of the reference rice, which was dried in shade. The treated brown rice was harder than the reference rice as indicated by the RVA analysis. Consistency of cooked rice was negatively correlated with stickiness was reported by Kumar *et al.* (1976). The water

insoluble amylose content of cooked rice seemed to be related to stickiness and consistency.

Improvement of cooking quality by applying steam to the freshly harvested paddy was made by Desikachar and Subramanyan (1957). Steamed sample showed fewer tendencies to pastiness. Steaming fresh paddy for 15-20 minutes and keeping the paddy hot for 1-2 hours before shade drying, rice which possessed the appearance and cooking quality of old rice was obtained. The consequences of parboiling treatment on the behavior of rice on cooking and other end use applications were important and merit some thorough investigations (Patindol *et al.,* 2008). The functional properties of milled rice obtained from parboiling rough rice and brown rice need to be clearly documented; hence, this study was undertaken to find the effect of hydrothermal treatments on pasting properties of flour obtained from grinding of parboiled brown rice.

2. Materials and methods

The present study was carried out in Department of Food Science and Technology, College of Agriculture, Punjab Agricultural University, Ludhiana.

2.1. Raw materials

Three varieties of paddy namely *PR-115*, *PR-118* and *Punjab mehak* were procured from Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana.

2.2. Hydrothermal treatments

Three treatments were given to paddy to study their pasting properties obtained after dehusking of paddy. The treatments were as follows:

1. Soaking paddy in water at room temperature for 2 hours followed by steaming for 15 minutes under atmospheric pressure and drying by conventional and microwave method.
2. Soaking paddy in water at room temperature for 2 hours followed by steaming for 5-10 minutes under 15-20 PSI pressure and drying by conventional and microwave method.
3. Soaking paddy in hot water (70±2°C) for 2-3 hours followed by steaming for 15 minutes under atmospheric pressure and drying by conventional and microwave method.

2.3. Milling

Paddy was shelled to obtain brown rice in Satake Rice Sheller. For each milling test, paddy samples (100 g each) were cleaned before passing through a Satake rubber roll huller (Model THU 35A, Japan). Broken rice was separated from head rice before packaging using a Satake grader (Model TRG05B, Japan) process. Head rice yield was determined three times.

2.4. Packaging

Brown rice were packed in PET jars, cloth bags, sealed plastic bags (HDPE) and vacuum packaging in plastic bags and studied for the pasting properties over a period of 4 months.

2.5. Pasting characteristics

A Rapid Visco Analyzer (RVA) model (AACC, 2000) was used to determine the pasting properties of brown rice using following procedure:

1. Switched on the RVA and allowed it to warm for 30 minutes prior to the experiment.
2. Weigh 3g (14 per cent moisture basis) of flour in canister.
3. Place the paddle into the canister and vigorously jogged the blade through the sample up and down 10 times or until it mixes uniformly.
4. Insert the canister into pre-adjusted instrument.
5. Initiate the measurement by depressing the motor tower of the instrument.
6. Remove the canister on completion of test and discard.

2.6. Storage studies

The brown rice samples were stored in different packages at ambient conditions to estimate the pasting behavior of treated brown

rice over a period of 4 months and samples were evaluated for pasting temperature, peak viscosity, hold viscosity, final viscosity, breakdown viscosity and setback viscosity at the interval of 1 month, during the storage period.

2.7. Statistical analysis of data

Data collected from aforesaid experiments was subjected to statistical analysis with the help of factorial design in CRD using CPCS1 computer program (Singh *et al.,* 1998). The readings were taken in a set of triplicate and data were presented in form of Mean±S.D.

3. Results and discussions

Samples of three varieties of rice viz. *PR-115*, *PR-118* and *Punjab mehak* were procured from Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana. Paddy was shelled to obtain brown rice in Satake Rice Sheller. Hydrothermal treatments were given to paddy. Treated paddy were milled to brown rice and packed in four different types of packages namely polythene packaging, jute/cloth bags, vacuum plastic bags and PET jars and stored under room temperature for 4 months. Brown rice was periodically assessed for changes in pasting characteristics (Rapid Visco Analyser). For convenience and proper presentation of data, abbreviations have been used in the subsequent part of results and discussion. Details of these abbreviations were given in Table 1.

Table 1. Description of experimental samples and the abbreviations used

Varieties (V)	**Abbreviation**
PR 115	V_1
PR 118	V_2
Punjab mehak	V_3
Treatments (T)	**Abbreviation**
Control	T_1
Soaking paddy in water at room temperature for 2 hours followed by steaming for 15 minutes under atmospheric pressure	T_2
Soaking paddy in water at room temperature for 2 hours followed by steaming for 5-10 minutes under 15-20 PSI	T_3
Soaking paddy in hot water (70±2°C) for 2-3 hours followed by steaming for 15 minutes under atmospheric pressure	T_4
Packaging materials	**Abbreviation**
Polythene packaging	**P_1**
Jute/cloth bags	**P_2**
Vaeeum plastic bags	**P_3**
PET jars	**P_4**
Storage period (S)	**Abbreviation**
0 day	**S_1**
1 month	**S_2**
2 months	**S_3**
3 months	**S_4**
4 months	**S_5**
Interactions	**Abbreviation**
Variety ×Treatment	**V×T**
Treatments ×Packaging	**T×P**
Treatments ×Storage period	**T×S**

Variety× Packaging	**V×P**
Variety× Storage period	**V×S**
Packaging × Storage period	**P×S**

Table 2. Effect of variety, treatments, packaging material and storage period on pasting temperature (°C) of brown rice

Variety	Treatment	Packaging Material	Storage Period				
			S_1	S_2	S_3	S_4	S_5
V_1	T_1	P_1	92.40±1.74	89.80±1.27	88.10±0.57	NR	NR
		P_2	92.10±1.74	89.90±1.56	88.50±0.64	NR	NR
		P_3	92.50±1.74	89.60±1.45	88.20±0.59	NR	NR
		P_4	92.30±1.74	89.80±1.25	88.30±0.51	NR	NR
	T_2	P_1	92.90±0.91	92.50±0.59	91.90±0.48	91.40±0.34	89.10±0.12
		P_2	92.80±0.91	92.40±1.86	91.70±0.44	91.20±0.38	89.00±0.58
		P_3	92.90±0.91	92.50±0.68	91.50±1.21	91.00±0.54	89.10±0.55
		P_4	92.10±0.91	92.60±1.23	91.70±0.24	91.20±0.61	89.00±0.61
	T_3	P_1	93.80±1.89	92.50±0.49	91.90±0.57	91.20±0.57	90.90±0.78
		P_2	93.90±1.89	92.40±0.53	91.50±0.67	91.00±0.61	90.70±0.49
		P_3	93.50±1.89	92.50±0.81	91.70±0.68	91.10±0.38	90.60±1.21
		P_4	93.60±1.89	92.50±0.89	91.60±0.68	91.00±0.46	90.70±0.49
	T_4	P_1	94.80±0.59	92.00±0.71	91.00±0.64	90.50±0.55	88.20±1.04
		P_2	94.70±0.59	92.10±0.76	91.10±1.24	90.20±0.68	88.20±1.02
		P_3	94.70±0.59	92.20±1.24	91.00±1.34	90.30±0.61	88.301±0.01
		P_4	94.80±0.59	91.80±1.54	91.20±1.57	90.10±0.49	88.10±0.59
V_2	T_1	P_1	85.70±0.44	85.00±1.35	84.50±0.84	84.00±0.52	83.60±0.81
		P_2	85.80±0.44	85.10±0.68	84.30±0.89	84.10±1.11	83.50±0.48
		P_3	85.70±0.44	85.30±1.27	84.20±1.24	84.20±1.34	83.20±0.49
		P_4	85.60±0.44	85.00±1.68	84.30±1.29	84.10±0.69	83.10±0.57
	T_2	P_1	89.50±0.57	89.00±1.38	88.40±1.37	88.10±0.97	87.00±0.29
		P_2	89.60±0.57	89.00±1.74	88.50±1.38	88.00±1.24	87.20±0.58
		P_3	89.50±0.57	89.10±0.88	88.40±0.58	88.00±0.59	87.20±1.16
		P_4	89.70±0.57	89.10±1.48	88.30±0.67	88.20±0.57	87.10±1.14
	T_3	P_1	92.70±1.24	91.70±0.59	90.90±1.27	87.00±0.64	85.90±0.91
		P_2	92.80±1.24	91.50±0.87	90.80±1.54	87.20±0.61	85.20±1.85
		P_3	92.90±1.24	91.70±1.24	90.50±1.38	87.00±1.23	85.30±0.95
		P_4	92.70±1.24	91.60±1.25	90.70±1.61	87.20±1.55	85.40±1.21
	T_4	P_1	92.40±1.32	92.00±0.76	91.00±1.28	89.50±0.87	88.20±1.35
		P_2	92.60±1.32	92.10±1.49	91.30±1.25	89.50±0.59	88.20±0.59
		P_3	92.50±1.32	92.00±1.57	91.00±1.36	89.20±1.08	88.00±0.69
		P_4	92.50±1.32	92.00±1.26	91.10±0.58	89.30±0.66	88.10±0.58
V_3	T_1	P_1	87.50±1.65	87.50±1.74	87.50±1.61	88.60±1.09	88.40±0.67
		P_2	87.50±1.65	87.60±0.58	87.40±0.83	88.50±1.15	88.10±0.59
		P_3	87.60±1.65	87.10±0.67	87.40±1.64	88.40±0.59	88.20±1.59
		P_4	87.60±1.65	87.10±1.27	87.50±0.79	88.50±0.47	88.10±1.22
	T_2	P_1	88.70±1.27	87.50±0.84	86.80±1.67	86.00±0.84	85.50±1.46
		P_2	88.90±1.27	87.40±1.67	86.60±1.59	86.20±1.32	85.40±0.59

		P_3	88.70±1.27	87.60±1.38	86.80±0.55	86.00±0.91	85.30±0.44
		P_4	88.60±1.27	87.50±1.67	86.50±0.59	86.30±0.57	85.40±0.68
	T_3	P_1	90.70±0.85	90.10±1.54	89.40±0.61	89.00±0.62	88.40±0.57
		P_2	90.60±0.85	90.00±1.61	89.20±0.47	89.30±0.55	88.30±1.23
		P_3	90.80±0.82	90.00±1.59	89.20±1.14	89.00±1.12	88.30±0.77
		P_4	90.70±0.85	90.10±1.49	89.30±1.12	89.10±0.69	88.20±0.81
	T_4	P_1	91.601±0.23	90.10±1.58	88.20±1.19	88.00±1.31	87.80±1.24
		P_2	91.70±1.23	90.30±1.64	88.10±0.67	88.20±0.51	87.80±1.51
		P_3	90.70±1.23	90.20±0.76	88.20±0.58	88.20±0.84	87.60±0.68
		P_4	90.60±1.23	90.20±0.81	88.00±0.54	88.00±0.86	87.90±0.59
CD (p≤0.05): V: 1.79, T: 1.26, S: 1.43, P: 0.38, VT: 1.13, VS: 1.06, TS: 0.79, SP: 0.27							

Table 3. Effect of variety, treatments, packaging material and storage period on peak viscosity (cP) of brown rice

Variety	Treatment	Packaging Material	Storage period				
			S_1	S_2	S_3	S_4	S_5
V_1	T_1	P_1	2415±2.11	2345±3.31	1386±3.35	448±1.25	440±1.04
		P_2	2415±2.11	2344±2.35	1387±3.16	449±1.35	441±1.22
		P_3	2415±2.11	2345±3.56	1386±3.96	447±1.18	442±1.18
		P_4	2415±2.11	2345±4.25	1386±4.15	448±1.37	440±1.31
	T_2	P_1	1988±6.24	1603±2.12	1580±1.88	1554±2.25	1550±2.15
		P_2	1988±6.24	1602±2.54	1580±1.64	1556±2.34	1552±2.27
		P_3	1988±6.24	1603±2.84	1581±2.54	1555±2.19	1551±3.18
		P_4	1988±6.24	1603±2.14	1580±2.35	1554±2.54	1550±2.51
	T_3	P_1	1965±3.21	1796±3.25	1750±6.01	1628±3.15	1601±3.27
		P_2	1965±3.21	1795±3.27	1751±1.28	1629±2.24	1600±2.59
		P_3	1965±3.21	1796±3.62	1750±3.35	1628±3.28	1600±2.58
		P_4	1965±3.21	1797±3.85	1750±2.64	1628±3.61	1599±2.41
	T_4	P_1	1954±4.53	1560±2.84	1550±2.57	1500±2.59	1459±2.38
		P_2	1954±4.53	1560±1.99	1548±1.84	1500±2.57	1458±2.59
		P_3	1954±4.53	1563±2.54	1550±2.51	1504±3.18	1459±2.34
		P_4	1954±4.53	1562±2.84	1551±3.12	1502±4.15	1460±1.28
V_2	T_1	P_1	2456±3.51	2384±2.15	2214±3.24	2049±2.94	1954±1.53
		P_2	2456±3.51	2385±3.14	2215±3.21	2048±3.27	1954±1.51
		P_3	2456±3.51	2386±3.05	2214±3.11	2045±2.59	1956±1.48
		P_4	2456±3.51	2384±3.09	2213±1.55	2048±2.51	1955±1.94
	T_2	P_1	1414±5.25	1401±3.54	1385±2.64	1354±2.48	1209±2.28
		P_2	1414±5.25	1400±3.18	1386±2.24	1355±2.61	1206±2.68
		P_3	1414±5.25	1400±3.24	1385±2.28	1357±2.52	1205±3.27
		P_4	1414±5.25	1402±2.19	1384±2.61	1354±2.38	1208±2.35
	T_3	P_1	1130±2.16	1117±3.14	1100±1.84	1094±3.15	1071±3.25
		P_2	1130±2.16	1115±2.25	1104±1.67	1095±3.29	1072±4.15
		P_3	1130±2.16	1114±1.49	1102±2.04	1095±3.48	1071±4.04
		P_4	1130±2.16	1118±1.08	1101±3.24	1094±4.12	1073±2.28
	T_4	P_1	1109±5.24	1101±2.18	1054±4.19	1004±4.08	958±1.35
		P_2	1109±5.24	1102±2.62	1055±1.83	1001±4.01	959±1.81
		P_3	1109±5.24	1099±2.51	1058±4.27	1000±2.35	957±2.29

		P_4	1109±5.24	1100±2.48	1055±5.08	1005±2.38	958±4.28
V_3	T_1	P_1	2345±6.14	1869±2.19	1850±4.29	1654±2.15	1524±1.29
		P_2	2345±6.14	1865±3.12	1851±3.25	1655±2.48	1525±4.28
		P_3	2345±6.14	1868±2.25	1852±3.17	1652±3.15	1524±4.29
		P_4	2345±6.14	1867 3.34	1855±3.28	1651±3.27	1523±2.28
	T_2	P_1	1603±4.53	1505±3.25	1484±3.41	1325±1.29	1124±1.59
		P_2	1603±4.53	1505±3.17	1485±3.37	1325±2.22	1125±2.58
		P_3	1603±4.53	1507±2.11	1484±3.27	1326±2.39	l124±2.39
		P_4	1603±4.53	1508±2.35	1484±2.52	1324±1.29	1124±2.18
	T_3	P_1	1364±3.54	1214±3.28	11012.61	1017±1.51	1005±2.48
		P_2	1364±3.54	1215±4.15	1100±2.38	1018±2.28	1005±3.15
		P_3	1364±3.54	1214±3.29	1101±2.41	1017±3.24	1004±3.04
		P_4	1364±3.54	1213±2.18	1102±2.62	1016±2.38	1006±3.08
	T_4	P_1	1192±2.36	1154±4.15	1148±3.12	1041±1.26	1011±2.09
		P_2	1192±2.36	1155±4.28	1149±2.35	1042±1.28	1012±2.12
		P_3	1192±2.36	1154±4.05	1147±4.12	1041±3.28	1011±2.18
		P_4	1192±2.36	1153±3.12	1148±2.35	1041±3.27	1011±2.28
CD (p≤0.05): V: 0.42, T: 3.32, S: 1.54, P: NS, V×T: 4.53, V×S: 1.78, T×S: 2.67, P×S: NS							

3.1. Effect of variety, treatment, packaging material and storage period on pasting temperature of parboiled brown rice

Studies were carried out to observe and analyze the effect of varieties, treatments, storage period and packaging material on pasting properties of parboiled brown rice flour. Samples of treated varieties were prepared, and the pasting properties were determined using the rapid visco analyser (RVA), starch master R&D pack V-3.0 (Newport Scientific, Narrabean, Australia). The parameters measured were pasting temperature (the temperature at which the viscosity of the paste starts to increase), peak viscosity (the maximum viscosity that the slurry attains), holding viscosity (the trough at minimum hot paste viscosity), final viscosity (the viscosity of the slurry after cooling to 50°C and holding the temperature), breakdown viscosity (peak-trough viscosity) and setback (final-trough viscosity) in accordance with the method given by Walker *et al.* (1988) and Batey *et al.* (1997). Hydrothermal treatments affect on the pasting temperature of parboiled brown rice flour significantly (Table 2). The pasting temperature increased with increase in hydrothermal treatments therefore pasting temperature was maximum for T_4 and minimum for T_1 i.e., control. Pasting temperature decreased with storage period from 94.8 cP on 0 day to 88.2 cP at the end of the storage period in case of variety V_1 and treatment T_4. The individual effect of varieties, treatments, storage period and packaging material were significant on pasting temperature of parboiled brown rice flour. Interactions of varieties with treatment, varieties with storage period, treatment with storage period and storage period with packaging material were found significant pasting temperature of parboiled brown rice flour. The higher hydrothermal treatment causes the increase in pasting temperature with processing.

3.2. Effect of variety, treatment, packaging material and storage period on peak viscosity (cP) of parboiled brown rice

The individual effect of varieties, treatments, storage period were significant while the individual effect of packaging material was insignificant on peak viscosity of parboiled brown rice flour (Table 3). Peak viscosities attained during the heating portions of the tests indicate that water binding capacity of starch. Peak viscosity decreased with storage from 2415 cP on zero day to 440 cP at the end of the storage in case of control of variety V_1

and from 1954 cP to 1459 cP in case of T_4. Peak viscosity decreased with treatments as control of V_2 has 2456 cP value but for T4 value decreased to 1109 cP. Packaging material insignificantly affect on peak viscosity of parboiled brown rice. Interactions of varieties with treatment, varieties with storage period and treatment with storage period were significant while interaction of storage period with packaging material were insignificant on peak viscosity (cP) of parboiled brown rice. The decrease in peak viscosity during aging of rice showed that the starch granules of aged rice were more resistant to swelling than that of fresh rice.

Dengate (1984); Dengate and Meredith (1984) reported that peak viscosity was dependent on swelling, exudation and fragmentation of starch. Peak viscosity is indicative of water binding capacity and ease with which starch was disintegrated and it was often correlated with final product quality (Thomas and Atwell, 1999). Mir *et al.* (2013) studied the effect of soaking temperature (60°C, 70°C and 80°C) on pasting properties using Rapid Visco Analyzer (RVA). The comparison of pasting profile of raw rice from different cultivars with parboiled rice showed that pasting profile of parboiled rice decreased as result of increased damaged starch which absorbs the water content and decreased peak viscosity resulting from the resistance of starch granules for swelling due to the gelatinization process takes place in parboiling.

Symons and Brennan (2004) suggested that a reduction in pasting characteristics could be associated with a reduced enthalpy of starch gelatinization and with retention of the integrity of starch granule, the reduction in peak viscosity being associated to reduced degree of starch granule swelling. It had been stressed that the endogenous presence and external addition of dietary fiber to starch based food systems involved nutritional benefits (Brennan and Samyue, 2004).

3.3. Effect of variety, treatment, packaging material and storage period on hold viscosity (cP) of parboiled brown rice

The individual effect of varieties, treatments and storage period were found significant while the individual effect of packaging material was insignificant on peak viscosity of parboiled brown rice flour (Table 4). Hold viscosity decreased with hydrothermal treatments as well as with storage. V_3 had higher values for hold viscosity followed by V_2 and V_1 in the order. Hold viscosity decreased from 1018 cP to 875 cP in case of V_3 under T_4. This showed that there was decrease in hold viscosity with increased storage period, thus fresh brown rice had higher hold viscosity than aged brown rice. The interactions of varieties with treatment, varieties with storage period, treatment with storage period and storage period with packaging material were found significant on hold viscosity (cP) of parboiled brown rice.

3.4. Effect of variety, treatment, packaging material and storage period on final viscosity (cP) of parboiled brown rice

Final viscosity of treated samples was less than control which depicts that final viscosity decreased with hydrothermal treatments however final viscosity increased with storage period (Table 5). Variety V_1 had higher final viscosity at the end of the storage followed by V_2 and V_3. Final viscosity varied significantly with respect to varieties, treatments, and storage. Packaging material did not affect the final viscosity significantly. The interactions of varieties with treatment, varieties with storage period, treatment with storage period and storage period with packaging material were found significant on final viscosity (cP) of parboiled brown rice. *PR-115* had higher final viscosity at the end of the storage followed by *PR-118*and *Punjab mehak.* The decreased final viscosity of sample with added fiber suggested that the three-dimensional network was weekend by the presence of fiber in matrix particularly by those of larger particle size and water in solubility.

Table 4. Effect of variety, treatments, packaging material and storage period on hold viscosity (cP) of brown rice

Variety	Treatment	Packaging Material	Storage period				
			S_1	S_2	S_3	S_4	S_5
V_1	T_1	P_1	1051±3.12	1024±2.38	1008±3.33	986±2.71	942±3.12
		P_2	1051±3.12	1023±2.38	1007±2.59	985±2.53	943 ±3.16
		P_3	1051±3.12	1024±2.63	1006±1.58	985±2.69	943±2.54
		P_4	1051±3.12	1023±2.63	1008±1.69	986±1.34	942±2.59
	T_2	P_1	987±4.05	974±1.35	955±1.88	941±1.29	847±1.59
		P_2	987±4.05	975±1.69	956±2.54	940±1.58	846±1.67
		P_3	987±4.05	976±1.48	956±2.69	943±2.65	845±1.18
		P_4	987±4.05	975±1.57	955±2.11	942±2.84	845±2.31
	T_3	P_1	884±3.24	851±2.38	846±3.27	789±1.59	748±2.61
		P_2	884±3.24	850±2.19	847±3.58	788±1.58	747±3.12
		P_3	884±3.24	850±3.29	846±1.59	789±2.59	747±3.05
		P_4	884±3.24	852±3.28	845±1.86	789±2.54	748±4.01
	T_4	P_1	761±2.59	754±3.15	737±2.54	712±1.59	701±1.25
		P_2	761±2.59	755±3.08	736±3.28	713±2.58	700±1.37
		P_3	761±2.59	754±2.19	735±2.66	713±3.24	700±1.67
		P_4	761±2.59	756±1.67	737±1.47	714±3.57	703±1.84
V_2	T_1	P_1	1331±3.31	1351±2.58	1254±1.69	1126±1.61	1109±1.66
		P_2	1331±3.31	1352±3.19	1255±2.59	1123±2.59	1108±2.54
		P_3	1331±3.31	1350±2.38	1256±1.94	1124±1.61	1107±2.61
		P_4	1331±3.31	1350±2.18	1256±1.68	1123±1.25	1105±3.16
	T_2	P_1	1314±2.24	1287±1.57	1200±2.98	1189±2.15	1158±3.24
		P_2	1314±2.24	1285±1.36	1202±3.48	1188±2.19	1160±3.25
		P_3	1314±2.24	1287±2.15	1200±3.24	1189±2.51	1162±1.67
		P_4	1314±2.24	1286±3.13	1201±1.86	l190±2.64	1161±2.46
	T_3	P_1	1128±1.58	1l09±2.65	1084±2.44	1057±5.01	984±2.59
		P_2	1128±1.58	1108±1.85	1086±3.11	1056±4.29	985±2.67
		P_3	1128±1.58	1109±0.99	1083±1.56	1055±5.03	985±5.31
		P_4	1128±1.58	1109±1.24	1083±1.48	1057±1.28	987± 5.02
	T_4	P_1	1106±2.61	1095±1.29	1081±1.67	1050±4.31	951±3.26
		P_2	I106±2.61	l096±2.38	1080±2.54	1050±2.59	955±2.31
		P_3	1106±2.61	1096±3.16	1082±2.68	1050±2.68	955±2.37
		P_4	1106±2.61	1095±2.65	1080±1.64	1051±2.95	954±2.36
V_3	T_1	P_1	1431±1.08	1239±2.69	1204±2.58	1186±3.54	1149±2.64
		P_2	1431±1.08	1235±3.16	1201±2.26	1185±2.54	1148±3.15
		P_3	1431±1.08	1235±2.18	1202±1.54	1185±2.84	1148±3.04
		P_4	1431±1.08	1236±3.24	1205±2.51	1185±1.87	1149±2.51
	T_2	P_1	1158±2.34	1051±1.55	1042±2.61	1004±1.95	987±2.35
		P_2	1158±2.34	1052±1.59	1045±2.24	1003±1.58	988±2.37
		P_3	1158±2.34	1052±2.58	1042±3.15	1004±1.68	988±3.09
		P_4	1158±2.34	1053±3.27	1043±2.24	1004±2.61	987±3.29
	T_3	P_1	1128±3.25	1114±1.48	1102±1.84	1059±3.24	981±2.54
		P_2	1128±3.25	1115±3.24	1102±1.38	1060±2.15	983±2.61
		P_3	1128±3.25	1116±1.58	1101±3.14	1062±2.34	982±2.29

		P_4	1128±3.25	1113±1.29	1100±2.59	1061±1.26	982±3.25
	T_4	P_1	1018±1.26	986±3.28	953±2.57	948±2.34	875±2.32
		P_2	1018±1.26	985±2.27	954±1.28	947±1.59	875±2.05
		P_3	1018±1.26	987±1.59	954±1.67	947±2.51	875±3.16
		P_4	1018±1.26	986±2.68	955±2.53	948±2.36	874±3.15
CD (p≤0.05): V: 3.85, T: 2.12, S: 5.43, P: NS, V×T: 3.54, V×S: 4.89, T×S: 2.45, P×S: 0.89							

Table 5. Effect of variety, treatments, packaging material and storage period on final viscosity (cP) of brown rice

Variety	Treatment	Packaging Material	Storage Period				
			S_1	**S_2**	**S_3**	**S_4**	**S_5**
V_1	T_1	P_1	2826±6.15	2876±4.36	2894±4.56	2921±6.14	2935±5.26
		P_2	2826±6.15	2875±5.25	2895±6.54	2922±4.12	2937±4.26
		P_3	2826±6.15	2876±7.12	2895±4.35	2921±4.25	2935±5.36
		P_4	2826±6.15	2876±4.35	2894±3.44	2921±4.36	2936±4.15
	T_2	P_1	2041±8.12	2310±8.15	2319±4.55	2514±4.89	2678±6.25
		P_2	2041±8.12	2300±6.25	2319±4.12	2515±5.14	2677±6.35
		P_3	2041±812	2312±4.24	2320±5.12	2516±5.61	2678±4.25
		P_4	2041±8.12	2306±2.59	2319±6.24	2515±7.12	2677±4.15
	T_3	P_1	1897±5.54	1899±8.12	1924±6.59	1957±4.36	2455±5.36
		P_2	1897±5.54	1899±7.09	1924±3.25	1958±5.32	2454±2.36
		P_3	1897±5.54	1898±5.35	1926±4.12	1958±4.65	2455±4.12
		P_4	1897±5.54	1899±4.68	1925±6.35	1957±5.36	2456±5.11
	T_4	P_1	1539±7.15	1654±5.45	1889±5.84	2214±6.14	2300±5.25
		P_2	1539±7.15	1655±4.35	1889±4.59	2215±5.23	2300±5.36
		P_3	1539±7.15	1654±6.15	1889±3.56	2215±4.36	2305±4.65
		P_4	1539±7.15	1655±4.25	1890±6.25	2214±8.24	2301±4.26
V_2	T_1	P_1	2736±4.75	2785±4.12	2814±1.28	2855±6.25	2876±5.25
		P_2	2736±4.75	2785±4.08	2815±6.24	2856±7.15	2875±3.15
		P_3	2736±4.75	2784±7.14	2817±5.36	2854±5.36	2877±6.25
		P_4	2736±4.75	2786±3.25	2818±4.24	2855±6.15	2874±4.58
	T_2	P_1	2438±6.23	2459±6.15	2514±5.26	2657±9.15	2718±7.25
		P_2	2438±6.23	2458±8.12	2513±7.38	2657±4.25	2719±8.15
		P_3	2438±6.23	2461±4.24	2514±7.25	2658±9.25	2718±4.69
		P_4	2438±6.23	2460±5.18	2516±8.15	2655±7.26	2714±4.15
	T_3	P_1	1715±5.25	1751±7.12	1854±4.25	1943±9.26	2018±8.15
		P_2	1715±5.25	1754±6.35	1854±5.38	1945±8.12	2015±4.25
		P_3	1715±5.25	1750±4.15	1856±5.65	1945±4.26	2016±6.35
		P_4	1715±5.25	1750±7.15	1855±5.01	1944±4.35	2018±7.15
	T_4	P_1	1701±7.65	1930±8.12	1988±5.12	2017±4.15	2248±4.59
		P_2	1701±7.65	1932±4.24	1987±5.35	2014±6.35	2245±6.58
		P_3	1701±7.65	1935±5.25	1988±4.65	2016±4.12	2248±6.25
		P_4	1701±7.65	1931±4.25	1985±4.23	2015±4.35	2249±5.36
V_3	T_1	P_1	2500±3.48	2558±4.25	2645±4.78	2697±4.26	2750±4.15
		P_2	2500±3.48	2557±4.36	2644±4.65	2997±4.26	2755±6.25
		P_3	2500±3.48	2555±4.25	2645±4.12	2698±5.01	2754±6.35
		P_4	2500±3.48	2557±4.25	2645±6.01	2699±5.36	2751±4.25

	T_2	P_1	2204±5.55	2230±4.89	2539±4.11	2559±6.25	2584±3.65
		P_2	2204±5.55	2231±5.25	2538±6.23	2560±6.58	2585±3.65
		P_3	2204±5.55	2234±6.32	2538±4.26	2561±5.36	2584±4.15
		P_4	2204±5.55	2232±4.25	2539±7.15	2560±4.15	2584±6.12
	T_3	P_1	2130±6.15	2154±4.65	2567±5.65	2660±2.56	2674±4.36
		P_2	2130±6.15	2155±6.25	2568±9.14	2661±3.25	2675±4.17
		P_3	2130±6.15	2154±5.15	2568±2.65	2660±3.66	2674±4.25
		P_4	2130±6.15	2156±7.12	2564±5.14	2660±4.15	2675±5.14
	T_4	P_1	1862±4.35	1941±2.36	1985±3.65	2417±5.12	2500±5.68
		P_2	1862±4.35	1940±3.25	1984±4.35	2418±4.65	2501±5.36
		P_3	1862±4.35	1940±6.25	1985±5.65	2418±4.15	2500±4.12
		P_4	1862±4.35	1942±4.15	1986±5.47	2416±4.11	2499±5.14
CD (p≤0.05): V: 1.79, T: 3.68, S: 6.23, P: NS, V×T: 3.45, V×S: 4.37, T×S: 6.45, P×S: 1.23							

3.5. Effect of variety, treatment, packaging material and storage period on breakdown and setback viscosity (cP) of parboiled brown rice

Breakdown viscosity is measure of the ease with which the swollen granules could be disintegrated. Higher breakdown viscosity in starches could be attributed to higher crystalline and lower amylose content. The individual effect of varieties, treatments and storage period were found significant while the individual effect of packaging material was found insignificant on breakdown viscosity of parboiled brown rice flour (Table 6). Breakdown values decreased with storage period from 331 cP on zero day to 229 cP at the end of storage period in case of T_4 of variety V_1. The decrease of breakdown viscosity might be due to the failure of complete pasting and swelling of starch granules induced by the reduction of water absorption of starch granules. The interactions of varieties with treatment, varieties with storage period and treatment with storage period had significant effect while interactions of storage period with packaging materials were found insignificant effect on breakdown viscosity of parboiled brown rice. Breakdown viscosity was regarded as measure of degree of disintegration of starch granule or substances. The gel formed at the end of RVA cooling cycle was essentially a three-dimensional network of inter wined amylase molecules incorporating dispersed swollen ruptured starch granules (Langton and Hermansoon, 1989).

Table 6. Effect of variety, treatments, packaging material and storage period on breakdown (cP) of brown rice

Variety	Treatment	Packaging Material	Storage Period				
			S_1	S_2	S_3	S_4	S_5
V_1	T_1	P_1	667±2.12	651±2.36	584±2.15	550±2.59	5l5±2.45
		P_2	667±2.12	650±4.26	585±3.25	548±2.36	5l4±1.25
		P_3	667±2.12	651±2.65	584±2.45	550±2.35	5l5±1.14
		P_4	667±2.12	652±2.36	584±2.68	551±1.14	517±1.11
	T_2	P_1	519±3.01	511±4.01	478±3.01	475±1.36	470±1.36
		P_2	519±3.01	510±2.15	478±3.24	478±1.26	472±1.26
		P_3	519±3.01	511±2.35	478±1.25	475±1.26	470±1.55
		P_4	519±3.01	512±3.36	478±1.36	476±1.45	471±1.36
	T_3	P_1	487±3.13	350±2.35	328±2.36	299±1.12	281±1.65
		P_2	487±3.13	353±3.14	329±1.45	298±2.36	280±1.85
		P_3	487±3.13	351±3.15	328±2.35	294±1.45	280±1.95

		P_4	487±3.13	3501±3.25	328±2.36	298±1.36	282±2.15
	T_4	P_1	331±2.25	324±2.45	285±1.46	264±1.35	229±2.36
		P_2	331±2.25	321±2.15	286±1.56	264±1.14	230±1.14
		P_3	331±2.25	324±2.14	285±1.48	264±1.26	230±1.26
		P_4	331±2.25	325±2.36	284±1.98	265±1.45	231±1.45
V_2	T_1	P_1	445±2.36	418±2.35	401±1.48	382±1.26	357±2.35
		P_2	445±2.36	418±2.35	400±1.68	382±1.15	358±2.36
		P_3	445±2.36	4l8±2.26	400±1.25	382±2.04	359±2.65
		P_4	445±2.36	417±1.24	402±1.44	381±2.02	357±2.14
	T_2	P_1	375±3.35	359±1.55	344±1.32	297±4.15	347±2.15
		P_2	375±3.35	359±1.65	344±1.31	297±2.65	348±2.48
		P_3	375±3.35	358±1.78	345±1.22	294±2.36	349±2.19
		P_4	375±3.35	360±1.45	346±2.02	298±1.26	347±2.36
	T_3	P_1	330±2.45	255±1.65	228±2.04	19±1.24	13±2.15
		P_2	330±2.45	254±1.36	230±1.33	18±3.25	12±1.14
		P_3	330±2.45	256±1.25	230±1.21	18±2.15	11±2.36
		P_4	330±2.45	254±4.01	231±2.05	19±2.35	12±2.25
	T_4	P_1	312±1.23	301±2.35	284±2.06	268±2.36	221±2.15
		P_2	312±1.23	302±1.24	285±1.14	269±2.15	220±2.11
		P_3	312±1.23	301±2.56	285±1.25	268±2.26	221±2.35
		P_4	312±1.23	300±3.01	284±1.35	264±2.15	221±1.56
V_3	T_1	P_1	450±1.54	430±2.15	418±2.04	400±2.35	391±1.44
		P_2	450±1.54	432±2.48	417±2.06	401±1.26	392±1.58
		P_3	450±1.54	430±1.65	417±1.24	402±1.25	395±1.59
		P_4	450±1.54	431±2.35	418±1.06	400±302	392±1.48
	T_2	P_1	445±1.68	437±1.84	421±2.15	338±2.15	321±1.94
		P_2	445±1.68	438±1.35	422±1.26	334±2.26	322±1.44
		P_3	445±1.68	435±1.05	426±1.25	339±2.14	324±1.26
		P_4	445±1.68	437±1.45	422±1.14	338±2.15	321±1.54
	T_3	P_1	236±3.36	220±1.25	214±1.36	187±2.35	181±1.36
		P_2	236±3.36	221±1.56	213±1.26	185±3.25	181±1.48
		P_3	236±3.36	220±1.36	214±1.45	185±1.35	181±1.47
		P_4	236±3.36	220±1.24	215±4.25	186±1.45	180±2.15
	T_4	P_1	174±2.45	170±1.45	168±3.25	165±1.36	157±2.35
		P_2	174±2.45	168±1.36	168±3.15	166±1.35	158±1.14
		P_3	174±2.45	169±1.25	167±1.26	166±1.25	158±1.35
		P_4	174±2.45	170±1.02	167±1.25	165±3.05	154±1.26
CD (p≤0.05): V: 1.34, T: 5.52, S: 3.34, P: NS, V×T: 4.43, V×S: 4.12, T×S: 2.67, P×S: NS							

The individual effect of varieties, treatments, storage period and packaging material were found significant on setback viscosity of parboiled brown rice flour (Table 7). Setback viscosity followed reverse pattern as of breakdown viscosity. Setback viscosity decreased with the treatment and increased with storage period. The setback values indicate the hardness of gel paste upon cooling which is indirect measurement of retrogradation of starches. Low setback viscosity values of hydrothermally treated flour samples indicated lesser tendency to retrograde or syneresis upon cooling. The interactions of varieties with treatment, varieties with storage period and treatment with storage period had

significant effect on setback viscosity while interactions of storage period with packaging materials had insignificant effect on setback viscosity of parboiled brown rice. The increased setback viscosity resulted into more syneresis this indicated higher tendency of starch retrogradation (Hagenimana *et al.*, 2005). High setback value was an indication of the amount of swelling power of starch and it was usually related to the amylase content of the starch. Hydrothermal treatments affect the pasting temperature significantly.

Table 7. Effect of variety, treatments, packaging material and storage period on setback (cP) of brown rice

Variety	Treatment	Packaging Material	Storage Period				
			S_1	S_2	S_3	S_4	S_5
V_1	T_1	P_1	741±2.25	851±1.11	884±1.49	919±2.65	990±1.49
		P_2	741±2.25	852±1.25	885±1.59	920±2.05	991±1.25
		P_3	741±2.25	853±1.36	885±1.49	919±2.18	992±1.36
		P_4	741±2.25	851±1.14	884±1.39	918±2.01	992±1.12
	T_2	P_1	746±2.69	812±1.75	847±1.25	901±2.04	910±1.21
		P_2	746±2.69	811±1.26	847±1.02	900±1.06	912±1.29
		P_3	746±2.69	813±1.25	847±2.09	900±1.25	14±1.47
		P_4	746±2.69	814±1.54	848±2.05	902±1.59	913±1.84
	T_3	P_1	718±2.45	739±1.59	782±2.35	814±1.54	845±1.14
		P_2	718±2.45	738±1.58	785±1.54	185±1.58	846±1.48
		P_3	718±2.45	739±1.48	782±2.48	815±1.25	845±1.29
		P_4	718±2.45	740±1.57	782±2.49	816±1.32	847±1.07
	T_4	P_1	697±1.36	711±1.59	724±2.58	768±1.33	778±1.03
		P_2	697±1.36	712±1.68	726±2.36	765±0.59	777±0.97
		P_3	697±1.36	713±2.15	725±2.14	766±1.24	779±0.48
		P_4	697±1.36	711±1.26	724±1.26	765±1.22	778±0.58
V_2	T_1	P_1	981±2.21	1055±1.54	1071±1.68	1082±1.59	1101±1.36
		P_2	981±2.21	1054±1.05	1070±1.35	1084±1.48	1100±1.24
		P_3	981±2.21	1055±2.22	1074±1.45	1082±0.29	1104±1.11
		P_4	981±2.21	1056±1.24	1071±1.18	1085±1.36	1105±1.48
	T_2	P_1	948±1.24	973±1.36	1004±1.09	1054±0.59	1070±1.59
		P_2	948±1.24	975±1.56	1000±1.02	1054±.68	1073±1.24
		P_3	948±1.24	974±2.35	1004±1.25	1054±0.99	1071±1.29
		P_4	948±1.24	975±2.15	1002±0.78	1055±1.25	1072±1.09
	T_3	P_1	550±3.15	568±2.65	571±0.99	598±1.48	645±1.49
		P_2	550±3.15	569±1.48	570±0.58	598±1.59	644±1.19
		P_3	550±3.15	568±1.85	574±0.69	599±1.68	643±1.35
		P_4	550±3.15	569±1.67	572±1.25	599±2.30	643±1.49
	T_4	P_1	519±2.22	554±1.05	562±1.48	584±1.02	645±1.59
		P_2	519±2.22	559±2.35	562±1.59	585±1.06	646±1.08
		P_3	519±2.22	554±1.04	563±1.48	584±0.84	647±1.27
		P_4	519±2.22	553±1.26	561±2.15	585±1.26	645±1.26
V_3	T_1	P_1	1200±2.5	1254±1.04	1357±2.36	1400±1.45	1401±1.49
		P_2	1200±2.5	1256±1.24	1358±1.69	1399±1.31	1400±1.20
		P_3	1200±2.5	254±1.50	1356±1.58	1401±1.32	1398±1.48
		P_4	1200±2.5	1255±2.15	1355±1.45	1402±1.04	1400±1.26

	T_2	P_1	918±1.24	957±1.04	981±1.29	1008±1.06	1046±0.84
		P_2	918±1.24	957±1.06	980±1.05	1008±1.27	1048±1.49
		P_3	918±1.24	957±2.15	981±2.22	1005±1.29	1047±1.22
		P_4	918±1.24	958±1.24	981±2.06	1007±1.29	1045±1.52
	T_3	P_1	931±2.26	942±1.26	955±2.04	982±1.18	1002±1.49
		P_2	931±2.26	941±1.24	956±2.02	982±0.26	1000±1.47
		P_3	931±2.26	942±1.28	956±1.45	982±0.88	1003±1.58
		P_4	931±2.26	942±1.59	954±1.58	983±1.12	1001±1.29
	T_4	P_1	713±1.24	728±1.47	800±1.26	817±1.25	844±1.47
		P_2	713±1.24	726±1.49	800±1.24	816±1.22	845±1.28
		P_3	714±1.24	725±1.19	801±0.49	816±1.36	847±1.45
		P_4	714±1.24	727±1.85	801±1.12	817±1.49	843±0.95
CD ($p \leq 0.05$): V: 4.56, T: 4.12, P:0.09, S: 3.43, V×T: 4.34, V×S: 4.56, T×S: 3.98, P×S: NS							

During setback the mixture was subsequently cooled, there is reassociation between starch molecules, especially amylose. Insufficient concentration usually caused the formation of gel and viscosity normally increased. Therefore, the control flour without any treatment had higher values of setback. The change in some of the pasting properties during aging could be attributed to starch granule characteristics. The change in breakdown viscosity indicated that the capacity of the starch granules to rupture after cooking was reduced significantly by aging of the starch granules. However, the final and setback viscosity increased with increasing rice storage duration. These results were due to the strong granules after storage, so some starch granules were not disrupted during cooking. Final and setback viscosity might occur by rearrangement of leached amylose and the granules which have not been disrupted (Noomhorm *et al.*, 1997).

4. Conclusions

Hot water treatment followed by steaming for 15 min was found to be best among all treatments. The change in some of the pasting properties during aging could be attributed to starch granule characteristics. The individual effect of varieties, treatments, storage period and packaging material were significant on pasting temperature of brown rice flour. Interactions of varieties with treatment, varieties with storage period, treatment with storage period and storage period with packaging material were found significant on pasting temperature and final viscosity of brown rice flour. The higher hydrothermal treatment causes the increase in pasting temperature with processing. The individual effect of varieties, treatments, storage period were significant while the individual effect of packaging material was insignificant on peak viscosity of brown rice flour. Interactions of varieties with treatment, varieties with storage period and treatment with storage period were significant while interaction of storage period with packaging material were insignificant. Final viscosity of treated samples was less than control which depicts that final viscosity decreased with hydrothermal treatments however final viscosity increased with storage period. The interactions of varieties with treatment, varieties with storage period, treatment with storage period and storage period with packaging material were found significant. The change in breakdown viscosity indicated that the capacity of the starch granules to rupture after cooking was reduced significantly by aging of the starch granules. However, the final and setback viscosity increased with increasing rice storage duration. *Punjab mehak* was best responsive to treatments and hence retained better functional properties upon storage.

5. References

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