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Physicochemical, functional, thermal and pasting properties of starches isolated from pearl millet cultivars

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Abstract

Physicochemical, functional, thermal and pasting properties of starches isolated from five cultivars of pearl millet (*Pennisetum glaucum*) were studied. Amylose contents of the starches varied from 15.64 to 19.46 g/100 g of starch. Swelling power of different starch samples was highly restricted as it varied from 2.03 to 14.5 g/g at a temperature range of 60 to 90°C. The solubility of starch samples ranged from 7.25 to 12.13 g/100 g at 90°C. Light transmittance value of cultivar 'HHB-67' starch suspension was significantly lower than the transmittance value of the starch suspensions from other pearl millet cultivars ($p < 0.05$). Pasting temperature of starch suspensions ranged from 88.1 to 90.2°C being the lowest and the highest for 'Pioneer 86M86' and 'HHB-67' cultivars, respectively. The paste from Pioneer 86M86 starch showed highest stability to shear force whereas, starch paste from Varun 666 and Pioneer 86M86 cultivars showed the higher set back ratio suggesting highest tendency to retrograde. The lowest T_o, T_p and T_c of 60.8, 67.1 and 74.1°C, respectively, were observed for starch from the cultivar 'HHB-67', whereas starch from cultivar 'Varun 666' showed the highest value for the same suggesting that the crystallite size and/or crystallite association within its granules are of higher order than starches from other cultivars. The retrogradation (%) was the highest for 'Pioneer 86M86' starch and it was the lowest for 'HHB-67' starch.

Introduction

Pearl millet (*Pennisetum glaucum*) is an important cereal grain in the Asian countries and is utilized in the preparation of many traditional foods (Akingbala and Rooney, 1990; Gaffa *et al*., 2002). India continues to be the single largest producer of pearl millet in the world, although the area has been declining in the traditional growing states. However, due to the presence of hard seed coat and high fiber content, it has poor consumer appeal. In addition, the presence of anti-nutritional compounds such as phenols and tannins reduces its preference and for this reason, it is not ideal in the preparation of weaning foods (Rao, 1987; Sharma and Kapoor, 1997).

Starch contributes greatly to the textural properties of various foods and has many industrial applications as a thickener, colloidal, stabilizer, gelling agent, bulking agent, water retention agent and adhesive. With increasing industrial demand for starches, there is a need to explore new and alternative sources of starch. Among the cereal starches, much research attention has been given to rice (Takeda *et al*., 1986; Hizukuri *et al*., 1989), wheat (Takeda *et al*., 1984; Shibanuma *et al*., 1996), barley (Takeda *et al*., 1999; Yoshimoto *et al*., 2000) and maize (Takeda and Preiss, 1993). Keeping in view of the increased applicability of starch in food systems, different cheap and efficient alternative sources of starches with good functional properties are being explored. Pearl millet being an underutilized poor man's food crop can be a cheap alternative source of starch as it has been reported to contain about starch (Freeman and Bocan, 1973). In spite of the fact that the starch in the pearl millet represents 59 to 80% of the endosperm, however, pearl millet starches have been studied less extensively as compared to other conventional sources of cereal and tuber starches. The pearl millet starch granules are slightly smaller than that of corn and sorghum starch granules (Freeman and Bocan, 1973) ranging from 8 to 12 µm in diameter. Starches from various Indian cultivars of pearl millet starch show greater variability in amylose content ranging from 18.3 to 24.6% (Singh and Popli, 1973). Hoover *et al.* (1996) reported pasting temperature of pearl millet starches as 90°C, which was higher than those of wheat (86°C) and corn (81°C) starches.

With the renewed interest in diverse usage of the millets, an understanding of the properties of their starches is necessary. This will provide useful

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information on the suitability of these grains in food processing industry. Keeping in view the applications of these grains in food processing industry, the present study was undertaken with the objective to study the functional, thermal and pasting properties of starches from pearl millet cultivars grown in India.

Materials and Methods

Five cultivars of pearl millet i.e. 'HHB67', 'Varun 666', 'Pioneer 86M86', 'Roagro 9444' and 'Shri Ram 8494' were procured from Chaudhary Charan Singh Haryana Agricultural University, Hisar (India). All the chemicals and reagents used in the investigation were of analytical grade. The millet grains were analyzed for physico-chemical properties like thousand kernel weight, bulk density, moisture, ash and crude fat content were determined using standard analytical methods (AACC, 2000).

Isolation of pearl millet starch

Millet grains were steeped in distilled water (1:2) containing 0.01% sodium azide to inhibit microbial growth at 4°C for 24 h. The excess water was decanted and the steeped and washed grains were ground in a Warning blender with sufficient water. The slurry was sieved on 85 mesh nylon bolting cloth. The left-overs (hulls, germ and endosperm) were re-slurried with water to float off the germ and hulls. The grinding, sieving and regrinding of the left over endosperm particles was repeated until the left-overs were essentially free of starch. The starch-protein slurry was centrifuged at 2000 rpm for 20 min. The supernatant was discarded and the protein layer on top of the starch removed with spatula. The starch was washed repeatedly by re-dispersing in distilled water and centrifuging until it appeared clean. The cleaned starch was air-dried on a glass plate for 12 h, re-dispersed in water and wet-sieved through 100-mesh screen. The starch passing through the screen was recovered by centrifugation (2000 rpm, 20 min; Remi centrifuge C34 model) and dried in hot air oven (Model NSW 143 of M/s Narang Scientific Works, India) at 40°C.

Physicochemical properties of starch

The starch was analyzed for its moisture, ash, crude fat, pH, acidity and amylose content. Moisture content of the starch samples was determined using hot air oven method. Ash content was determined using standard method of AOAC (1995). Fat content was determined using Soxhlet extraction method. pH and titrable acidity were determined using methods of AACC (2000) and Rangana (1977) respectively. Amylose content of the isolated starch was determined by using the rapid colorimetric method of Williams *et al.* (1970) using the given standard regression equation.

Functional properties of starch

The functional properties such as water binding capacity (WBC), solubility and swelling power, transmittance and viscosity were determined using standard methods. WBC (%) of starch was determined dispersing 5 g of starch in 75 ml of water following the method of Yamazaki (1953) as modified by Medcalf and Gilles (1976). The swelling power and water solubility of pearl millet starch were measured at temperature ranging from 60 to 90°C using method given by Schoch (1964) with slight modification and the results were expressed as g/g of dry starch. Light transmittance (%) of the isolated starch samples was measured as described by Craig *et al.* (1989) using an aqueous suspension (2%) of starch heated in a water bath to 90°C for 1h with constant stirring.

Pasting properties of starch

Pasting properties of starch were evaluated with Rapid Visco-Analyzer (RVA Starch Master, Newport Scientific, Warriewood, Australia). Test profile STDI (Newport Scientific Method1, Version 5, 1997) was used for determination of pasting characteristics. A programmed heating and cooling cycle was used where the starch suspension (6%, w/w) was held at 50°C for 1 min, heated to 95°C at 6°C/min, held at 95°C for 2.7 min before cooling from 95 to 50°C at 6°C/min and holding at 50°C for 2 min. The pasting curve obtained were analyzed using a RVA Starch Master Software setup Tool (SMST) to obtain the characteristic parameters like pasting temperature (Ptemp); peak viscosity (PV, maximum paste viscosity achieved in the heating stage of the profile); hot paste viscosity (HPV, minimum paste viscosity at 95°C); cool paste viscosity (CPV, final viscosity at 50°C); breakdown (BD = PV-HPV); set back (SB = CPV-PV), consistency (CS = CPV-HPV), stability ratio (HPV/PV) and set back ratio (CPV/HPV). All measurements were taken in triplicate.

Thermal properties

Differential Scanning Calorimetry (DSC) studies were performed using a DSC (Perkin-Elmer Corp., Norwalk, CT) equipped with a digital DEC-425 thermal analysis data station. The instrument was calibrated using indium and purified, deionised distilled water as standards. Starch sample (3.5 mg, dwb) was weighed directly into aluminium pans, followed by addition of 8 ml of purified, deionised distilled water. The pans were hermetically sealed and allowed to equilibrate at room temperature overnight. A sealed aluminium pan containing 8 ml of purified, deionised distilled water was used as a reference. Samples were heated from 40 to 130°C at a rate of 10°C/min. Enthalpy (ΔH), onset (T_o), peak (T_p), and conclusion (T_c) temperatures were computed automatically. The gelatinization temperature range (*R*) and peak height index (PHI) were calculated as ($T_c - T_o$) and $\Delta H/(T_p - T_o)$ respectively, as described by Krueger *et al.* (1987).

After conducting thermal analysis, the samples were stored in a refrigerator at 4°C for 7 days for retrogradation studies. These samples were left at 28 °C for 2 h before analysis. The sample pans containing the starch were reheated at the rate of 10°C/min from 25 to 100°C. The enthalpy of retrogradation was calculated automatically and % retrogradation (% R) was calculated as:

$$\% R = \frac{\text{enthalpy of retrogradation}}{\text{enthalpy of gelatinization}} \times 100$$

Statistical analysis

Statistical analysis of the results was conducted using Minitab statistical software version 14 (Minitab Inc, State College, PA, USA). The data reported in all tables are an average of triplicate observations subjected to one-way analysis of variance (ANOVA).

Results and Discussion

Chemical composition of starch

The chemical composition of pearl millet starches from different cultivars is shown in Table 1. Ash content of starches ranged from 0.11 to 0.12%. Ash content of pearl millet starch has been reported to be in the range of 0.10 to 0.13% for different African cultivars (Beleia *et al*., 1980). Fat content of pearl millet starches ranged from 0.19 to 0.23% being lowest for 'Pioneer 86M86' and highest for 'Shri Ram 8494' starch. The moisture level of the starch samples was within the recommended moisture levels 13% for safe storage. Amylose content of starches varied significantly and ranged from 15.64 to 19.46 g/100 g of starch, being highest for the cultivar 'Roagro 9444' and the lowest for 'HHB-67'. However, Jambunathan and Subramanian (1988) reported high amylose content ranging from 21.9 to 28.8% for pearl millet starches. Beleia *et al.* (1980) reported amylose content of pearl millet starches in a narrow range of 22 to 24%.

Water binding capacity

Water binding capacity of starches from different pearl millet cultivars ranged from 83.27 to 88.84% being highest for the 'Roagro 9444' and lowest for 'Pioneer 86M86' cultivar starch. Beleia *et al.* (1980) reported water binding capacity in the range from 83.6 to 99.5% for starches isolated from various African pearl millet cultivars. Variations in water binding capacity may be caused by inherent differences in proportion of crystalline and amorphous areas in the granules. Starches containing a higher proportion of amorphous material would presumably have more water binding sites thus absorbing more water (Lawal, 2004).

Table 1. Physicochemical properties of starches from different pearl millet cultivars

Cultivars	Ash (%)	Fat (%)	Moisture (%)	Acidity	pH	Amylose
HHB-67	0.107±0.015[a]	0.217±0.005[ab]	8.27±0.09[c]	0.056±0.001[a]	6.83±0.11[e]	15.64±0.135[a]
Varun 666	0.123±0.005[b]	0.220±0.010[ab]	7.94±0.05[b]	0.079±0.001[a]	6.46±0.05[b]	18.33±0.200[d]
Pioneer 86M86	0.107±0.015[a]	0.187±0.005[a]	9.37±0.06[e]	0.066±0.001[a]	6.7±0.01[d]	17.57±0.240[c]
Roagro 9444	0.110±0.017[ab]	0.193±0.015[a]	7.47±0.19[a]	0.085±0.000[a]	6.43±0.05[a]	19.46±0.295[e]
ShriRam 8494	0.113±0.011[ab]	0.233±0.005[b]	8.87±0.07[d]	0.072±0.001[a]	6.6±0.05[c]	16.86±0.141[b]

The values are expressed as the mean of three replicate samples ± SD. Values with similar superscripts in a column do not differ significantly ($p < 0.05$)

Swelling power

Swelling power of different starch samples varied from 2.03 to 14.5 g/g with change in temperature from 60 to 90°C as shown in Figure 1. According to Schoch and Maywald (1968), this swelling behavior of pearl millet starches can be considered as highly restricted as swelling power was below 16 g/g. Starches showing restricted swelling behavior are relatively stable against shearing action during cooking in water (Galvez and Resurreccion, 1992). The swelling capacity was observed to be a function of temperature and the average value of swelling capacity increased significantly ($P < 0.05$) with increase in temperature. Starch from 'Shri Ram 8494' cultivar showed the highest swelling power at 90°C, whereas, reverse was true for starch from 'Pioneer 86M86' cultivar at 90°C. The swelling power and solubility provide evidence of the magnitude of interaction between starch chains within the amorphous and crystalline domains. The swelling behavior of starch depends mainly on the amylose content, structure of amylose and amylopectin, and presence of non-carbohydrate substances, especially in the presence of lipids acting as inhibitor of swelling (Tester and Morrison, 1990).

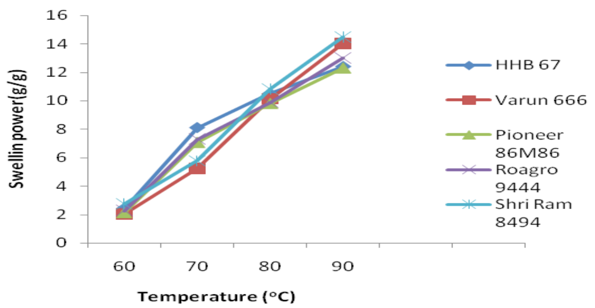

Figure 1. Swelling power (g/g) of starches from different pearl millet cultivars as affected by temperature

Solubility

Solubility of starch is an indicator of the degree of starch granules dispersion after cooking. Solubility behaviour of pearl millet starches at various temperatures (60 to 90°C) is as shown in Figure 2. It was found that solubility increased with increase in temperature for pearl millet starches. Starches with low swelling and solubility at temperature below 75°C had high swelling at temperature 80°C or above. This phenomenon could be related to the two stage relaxation of bonding forces within the starch granules during swelling. Solubility of the 'Shri Ram 8494' cultivar starch at 80 and 90°C was the highest, whereas the 'Pioneer 86M86' cultivar starch showed the lowest solubility at these temperatures. The solubility could imply to the amount of amylose leaching out from starch granule when swelling, therefore the higher the solubility the higher will be the amylose leaching (Srichuwong *et al*., 2005). Difference in solubility could also be attributed to different chain length distribution in the starch (Bello-Perez *et al*., 2000).

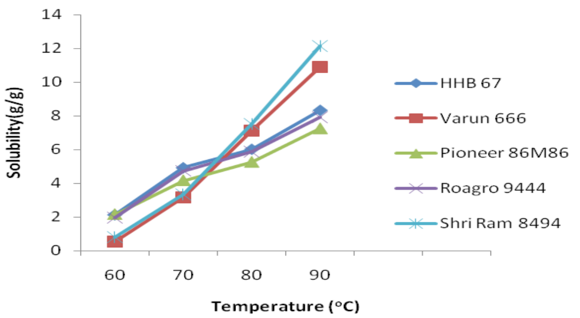

Figure 2. Water solubility (g/g) of starches from different pearl millet cultivars as affected by temperature

Light transmittance

Light transmittance indicates the clarity of a cooked starch paste. Pearl millet starches granules are fragile during pasting and remnants of granules are largely absent from the paste. The value of light transmittance within seven days of storage period ranged from 1.1 to 2.6% for different cultivars (Table 2). Light transmittance value for 'Shri Ram 8494' cultivar starch suspension dropped at higher rate from 2.6 to 1.5%, whereas the cultivar 'Varun 666' starch suspension had much lower drop in the transmittance (1.8-1.4%). Light transmittance value of cultivar 'HHB-67' starch suspension was significantly lower than the transmittance value of the starch suspensions from other pearl millet cultivars ($p < 0.05$). The lowest transmittance value for cultivar 'HHB-67' starch suspension may be attributed to its lowest amylose content and smallest granular size (Jacobson *et al*., 1997). The phosphate-monoester derivatives have been reported to increase paste clarity, whereas phospholipids have been reported to make starch paste opaque (Schoch, 1964, Kasemsuwan and Jane, 1996). Amylose and amylopectin with long chain tend to retrograde rapidly which affects the light transmittance of starch paste during storage.

Table 2. Effect of storage duration on light transmittance (%) of gelatinized starches from different pearl millet cultivars stored at 4°C

Storage days	HHB-67	Varun 666	Pioneer 86M86	Roagro 9444	Shri Ram 8494
1st day	$1.99±0.01^{b}$	$1.80±0.02^{a}$	$2.30±0.03^{c}$	$2.50±0.04^{d}$	$2.60±0.03^{e}$
2nd day	$1.90±0.02^{b}$	$1.70±0.04^{a}$	$2.20±0.05^{c}$	$2.40±0.05^{d}$	$2.50±0.04^{e}$
3rd day	$1.70±0.04^{a}$	$1.69±0.04^{a}$	$2.10±0.03^{b}$	$2.30±0.03^{c}$	$2.21±0.03^{bc}$
4th day	$1.60±0.04^{a}$	$1.60±0.04^{a}$	$2.09±0.02^{bc}$	$2.29±0.03^{c}$	$2.00±0.05^{b}$
5th day	$1.50±0.03^{a}$	$1.59±0.04^{ab}$	$2.00±0.01^{b}$	$2.10±0.03^{c}$	$1.99±0.03^{b}$
6th day	$1.33±0.02^{a}$	$1.50±0.04^{b}$	$1.80±0.03^{cd}$	$2.00±0.02^{d}$	$1.70±0.04^{c}$
7th day	$1.10±0.03^{a}$	$1.40±0.05^{ab}$	$1.80±0.04^{bc}$	$1.99±0.03^{c}$	$1.50±0.04^{b}$

The values are expressed as the mean of three replicate samples ± SD. Values with similar superscripts in a row do not differ significantly ($p < 0.05$)

Pasting properties

The pasting properties of starches from different pearl millet cultivars measured using RVA are presented in Table 3. Starches from different cultivars displayed a significant variation in all their pasting parameters. The starch suspensions showed gradual increase in viscosity with increase in temperature. The increase in viscosity with temperature may be attributed to the removal of water from the exuded amylose by the granules as they swell. PV is an indicator of water binding capacity and ease with which the starch granules are disintegrated and often correlated with final product quality (Thomas and Atwell, 1999). Peak viscosity (PV) of different starch samples was observed to be in the range from 1665 to 1998 cP, the lowest for 'Pioneer 86M86' starch and the highest for 'Varun 666' starch. Breakdown viscosity (BV) of starch from different pearl millet cultivars differed significantly ($p < 0.05$). Breakdown viscosity ranged from 414 to 769 cP. The breakdown is caused by disintegration of gelatinized starch granules structure during continued stirring and heating, thus, indicating the shear thinning property of starch (Yadav *et al*., 2011). A low breakdown value suggests the stability of starches under hot conditions. Amylose content is believed to have a marked influence on the breakdown viscosity (measure of susceptibility of cooked starch granule to disintegration) and the setback viscosity (measure of recrystallization of gelatinized starch during cooling) (Lee *et al*., 1995). Lower level of amylose to reinforce the molecular network within the granules resulted in greater breakdown viscosity. High amylose content has also been suggested as the major factor contributing to the non-existense of a peak, a high stability during heating, and a high setback during cooling (Lii and Chang, 1981, Karim *et al*., 2000).

Table 3. Pasting properties of starches from different pearl millet cultivars

Cultivar	P_{Temp} (ºC)	PV (cP)	BD	HPV (cP)	SB	CPV (cP)	Stability ratio	Set back ratio
HHB-67	90.2±0.20^{d}	1946±4.58^{cd}	582	1364±6.55^{c}	46	1991±9.64^{ab}	0.70	1.45
Varun 666	89.5±0.25^{c}	1998±7.50^{d}	586	1412±7.09^{d}	478	2476±7.54^{d}	0.71	1.75
Pioneer 86M86	88.1±0.15^{a}	1665±7.54^{a}	414	1251±7.93^{b}	502	2167±8.54^{c}	0.75	1.73
Roagro 9444	89.6±0.20^{c}	1741±5.29^{b}	578	1223±3.60^{b}	326	2067±10.01^{b}	0.70	1.69
Shri Ram 8494	88.6±0.26^{b}	1923±6.02^{c}	769	1154±8.18^{a}	8	1931±9.53^{a}	0.60	1.67

P_{Temp} = Pasting temperature, PV = Peak viscosity, BD = Breakdown, HPV = Hot paste viscosity, SB = Setback, CPV = Cold paste viscosity

Setback viscosity of pearl millet starches ranged from 627 to 1064 cP, the highest for 'Varun 666' and the lowest for 'HHB-67' starch. Final viscosity indicates the ability of the starch to form a viscous paste. Final viscosity of pearl millet starches ranged from 1931 to 2476 cP being the highest for 'Varun 666' cultivar. A higher final viscosity relates to the high resistance to shear. Increase in final viscosity might be due to the aggregation of the amylose molecules. Pasting temperature of starch suspensions ranged from 88.1 to 90.2°C being the lowest and the highest for 'Pioneer 86M86' and 'HHB-67' cultivars, respectively. Stability ratio explains the resistance of a starch paste to viscosity breakdown as shear is applied. The paste from Pioneer 86M86 starch was most stable to shear (stability ratio 0.75) whereas, the starch paste from Shri Ram 8494 was least stable to shear (stability ratio 0.60). It showed that there was improved organization within the starch granules of Pioneer 86M86 cultivar starch leading to more gradual swelling and less mechanical damage. Setback ratio, which is an indication of starch retrogradation tendency after gelatinization, was highest (1.75) in case of starch paste from Varun 666 and lowest (1.45) for HHB-67 starch.

Thermal and retrogradation properties

Differential Scanning Calorimeter (DSC) is an effective technique for analyzing the melting characteristics of crystallites. The gelatinization transition temperatures (onset, T_o; peak, T_p; and conclusion, T_c), enthalpy of gelatinization (ΔH_{gel}), peak height index (PHI) and gelatinization temperature range (R) of pearl millet starches are summarized in Table 4. The lowest T_o, T_p and T_c of 60.8, 67.1 and 74.1°C, respectively, were observed for starch from the cultivar 'HHB-67', whereas starch from the cultivar 'Varun 666' showed the highest value for the same. The higher gelatinization temperatures for 'Varun 666' starch indicated that more energy was required to initiate starch gelatinization. The higher T_o, T_p and T_c of 'Varun 666' starch suggests that the crystallite size and/or crystallite association within its granules are of higher order than starches from other cultivars. Enthalpy of gelatinization (ΔH_{gel}) indicates the amount of energy required to gelatinize the starch. ΔH_{gel} for various pearl millet starches ranged from 11.3 and 12.7 J/g. being highest (12.7 J/g) for 'Pioneer 86M86' starch and lowest (11.3 J/g) for 'Roagro 9444' starch. ΔH_{gel} reflects the loss of double helical rather than crystalline order (Cooke and Gidley, 1992). The variation in ΔH_{gel} could represent differences in bonding forces between the double helices that form the amylopectin crystallites, which resulted in different alignment of hydrogen bonds within starch molecules (McPherson and Jane, 1999). Amylopectin plays a major role in starch granule crystallinity, the presence of amylose lowers the melting point of crystalline region and the energy for starting gelatinization (Flipse *et al.*, 1996). PHI, a measure of uniformity in gelatinization, was found to be the lowest (1.84) for 'HHB-67' starch, whereas it was the highest (2.57) for 'Shri Ram 8494' starch. The higher value of 'R' suggested the presence of crystallites of varying stability within the crystalline domains of its granule (Hoover *et al.*, 1997).

Table 4. Thermal properties of starches from different pearl millet cultivars

Cultivars	T_o(°C)	T_p(°C)	T_c(°C)	ΔH_{gel}(J/g)	PHI	R	Δh_{ret} (J/g)	%R
HHB-67	60.8±0.15^{a}	67.1±0.23^{a}	74.1±0.10^{a}	11.60±0.10^{b}	1.84±0.10^{a}	13.30±0.05^{b}	5.63±0.10^{a}	48.53±0.24^{a}
Varun 666	64.2±0.25^{cd}	69.9±0.1^{c}	78.0±0.15^{e}	12.13±0.11^{c}	2.14±0.07^{a}	13.73±0.34^{b}	6.86±0.15^{c}	56.64±0.88^{d}
Pioneer 86M86	61.6±0.20^{b}	68.0±0.25^{a}	75.6±0.17^{b}	12.70±0.10^{e}	1.99±0.00^{a}	13.96±0.15^{b}	7.73±0.05^{d}	60.87±0.65^{e}
Roagro 9444	63.7±0.20^{c}	68.7±0.17^{b}	76.3±0.11^{c}	11.30±0.01^{a}	2.27±0.15^{a}	12.56±0.15^{a}	6.16±0.15^{b}	54.60±0.25^{c}
Shri Ram 8494	64.8±0.15^{d}	69.6±0.15^{c}	77.2±0.10^{d}	12.43±0.05^{d}	2.57±0.04^{a}	12.43±0.11^{a}	6.33±0.05^{bc}	50.93±0.23^{b}

T_o = onset temperature, T_p = peak temperature, T_c = conclusion temperature, R = gelatinization range (T_c-T_o), ΔH_{gel} = enthalpy of gelatinization (dwb, based on starch weight), PHI = peak height index ΔH_{gel} / (T_p- T_o), ΔH_{ret} = enthalpy of retrogradation, %R = percentage of retrogradation.
The values are expressed as the mean of three replicate samples ± SD.
Values with similar superscripts in column do not differ significantly ($p < 0.05$).

The molecular interactions (hydrogen bonding between starch chains) that occur after cooling of the gelatinized starch paste are known as retrogradation (Hoover, 2000). The retrogradation properties of pearl millet starches were studied after storage of gelatinized starch at 4°C for 7 days. The endothermic peaks of gelatinized and stored starch samples appeared from 45.63 to 66.20°C. ΔH_{ret} for pearl millet starches ranged from 5.63 to 7.73 J/g. The difference in ΔH_{ret} among various pearl millet starches suggested difference in their tendency towards retrogradation. The transition temperatures of retrogradation were found to be lower than the gelatinization temperatures. This might be due to the fact that recrystallization of branched chains of amylopectin occurred in a less ordered manner on stored gels, as it is present in native form. The retrogradation (%) was the highest for 'Pioneer 86M86' starch and it was the lowest for 'HHB-67' starch. These results regarding retrogradation tendency of starch pastes were in agreement with those obtained pasting properties as measured using rapid visco-analyzer RVA study also revealed lowest set back ratio for HHB-67 starch paste and second highest set back ratio for Pioneer 86M86 starch paste. The differences in ΔH_{ret} among different starches may be due to difference in amylose-amylopectin ratio, granular structure and phosphate esters (Hizukuri *et al*., 1983; Kasemsuwan *et al*., 1995; Hizukuri, 1996).

Conclusion

Results of the present study revealed non-significant variation in chemical composition of starches obtained from five cultivars of pearl millet. Starch from 'Roagro 9444' cultivar had the highest amylose content as well as water binding capacity. Swelling of the pearl millet starches can be considered as highly restricted and the starches showing restricted swelling behavior are relatively stable against shearing action during cooking in water. Small variations in the amylose content (15-18%) of starches from different cultivars indicated that the factors other than amylose content such as granular dimensions may be more important in determining the characteristics of the pearl millet starches.

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