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Functional Properties of Potato Flour and its Role in Product Development – A Review

Ramesh Y. Avula* • Rakesh K. Singh

Department of Food Science and Technology, University of Georgia, Athens GA 30602 USA

Corresponding author: * **aramesh@uga.edu**

ABSTRACT

Potato flour is a viable value added product due to its versatility in function as a thickener and color or flavor improver. It is used in bakery products, sauces, gravy, extruded products or fabricated snacks and also in dry soup mixes. Potato flour is prepared by drying the peeled slices in a hot air drier or by drying the cooked mash in a drum drier into flakes followed by grinding and sieving. The severity of heat treatment during the drying process influences the changes/degradations of starch and properties of flour. Flour properties can also be modified by chemical and enzymatic treatments and the properties such as paste viscosity, dough rheology, gel forming properties, swelling ability are important in determining suitability of flour in food formulations. The high stability of drum dried and hot air dried flours during heating and cooling processes demonstrates their possible use in products requiring sterilization such as baby food. Enzyme modified flours with high paste viscosities act as good thickeners. The functional properties of potato flour made by different processes involving physical, chemical or enzymatic treatments are discussed.

Keywords: paste viscosities, texture profile, thermal properties

CONTENTS

INTRODUCTION

Processing of potato into flour is the most satisfactory method of creating a product that is not only functionally adequate, but also remain for an extended period without damage. Potato flour can become a highly viable value added product due to its versatility in function as a thickener and color or flavor improver (Hadziyev and Steele 1979; Avula *et al*. 2006; Raj *et al.* 2008). Several products are prepared by incorporating potato flour with other flours and using the processes like baking, roasting, steaming, boiling and deep fat frying (Gahlawat and Sehgal 1996). Potato flour is incorporated in bread to retain its freshness. It also imparts a distinctive, pleasing flavour and improves toasting qualities and can be used advantageously in crackers, pastries, yeast raised doughnuts, cake and cake mixes. Products such as *gulab jamun*, and *paratha* containing potato flour were more acceptable than those made with wheat flour alone (Kulakarni *et al.* 1996). Rekha *et al.* (2009) formulated soup mix using modified potato flour with reduced paste viscosities. Marwaha and Sandhu (1996) reported the use of potato flour as a combined thickener - flavoring agent in dehydrated soups, gravies, sauces and baby foods. Nath and Chatopadhyay (2008) developed ready to eat snack using high temperature short time air puffing, and Bastos-Cardoso *et al.* (2007) developed extruded pellets of whole potato flour by microwave heating. The suitability of potato varieties for a particular process depends upon their nutritional composition such as the dry matter content, sugars, protein and other nitrogenous compounds. Studies on storage and microbial safety of potato flour revealed that the flour can be kept safely in polyethylene pouches for six months at room temperature and refrigerated temperature without any spoilage (Mishra and Kulshrestha 2002).

Potato flour ranks quite high in its supply of principal nutrients like protein, fiber and carbohydrates. Its protein content is superior to that of cassava and yam flour, and similar to that of rice. Potato flour has higher levels of fiber than refined wheat flour, maize meal, and rice. Its carbohydrate and energy contents are comparable to those of similar foods (Kulakarni *et al.* 1996). The average composition of potato flour is given in **Table 1**. Specialty flours in snack foods serve as functional ingredients, contributing to desirable attributes such as increased expansion, improved crispness, reduced oil pickup, and better overall eating qua-

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Invited Mini-Review

Table 1 Proximate composition of potato flour.

Characteristic	g/100 g*
Protein (N × 6.25)	9.1 ± 0.1
Carbohydrates	75.3 ± 1.0
Fat	0.3 ± 0.02
Total dietary fiber	10.6 ± 0.5
Ash	3.0 ± 0.1
Phosphorous	0.5 ± 0.01

*dry weight basis

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lity. The special rheological properties obtained by modifications have made the frozen, instant, encapsulated, and heat serve foods and cold water swelling products economically competitive (Sajilatha and Singhal 2005).

Potato flours are prepared by drying the peeled slices in a hot air drier or by drying the cooked mash by a drum drier into flakes, followed by grinding and sieving (Willard and Hix 1987; Avula *et al*. 2006; Bastos-Cardoso *et al*. 2007). Drying results in lowering the moisture content of the product thus leading to reduced chances of microbial growth. The reduction in moisture content is accompanied by reduction in bulk, which facilitates storage, transportation and packaging. However, the characteristics of the flour prepared by the above methods will be altered due to the involvement of heat treatment. Lamberti *et al*. (2004) studied the starch transformation during production and reconstitution of potato flakes. Composition of starch and flour was found to affect swelling power and solubility (Jangchud *et al*. 2003). The most important reaction in the modification of food starches is the introduction of substituent chemical groups. These chemical modifications are of two types, monofunctional; di- or polyfunctional. The number of reaction groups determines the manner in which a chemical modifier will alter rheological properties. Monofunctional reagents react with one or more hydroxyl groups per sugar unit to alter the polarity of the unit, sometimes making it ionic, and markedly influence the rheological properties of the starch. Acetic anhydride is a monofunctional reagent most often used for food starch modifications. It reacts to produce starch acetate (ester linkage) (Moore *et al*. 1984). The physico-chemical properties of acetylated starches depend on their chemical structure, degree of substitution (DS) and acetyl group distributions (Wang and Wang 2001; Gonzalez and Perez 2002; Lawal 2004; Singh *et al*. 2004). Acetylated potato flour was prepared by mixing native potato flour (prepared by drying the potato slices at 40°C and milled into flour and sieved) with solid $NaHCO_3$, followed by treating with acetic anhydride (Avula *et al*. 2007a).

In the *in vitro* alpha amylolysis of different starch granules, the enzyme attack is rather restricted and is usually from outside inwards, i.e. exocorrosion (Bhat *et al*. 1983). On the other hand, *in vivo* the granules are subjected to cumulative actions of dilute acid (by gastric juices) and pancreatic alpha amylase, and as a result the granules are better digested. The enzyme from *A. awamori* has been shown to have separate active site and raw starch adsorbability characteristics (Hayashida *et al*. 1989). The latter, in addition to its adsorption on to the granule, played a specific role in raw starch digestion. The granule degradation was mostly confined to pitting and surface erosion all over. In the case of alpha amylolysis, it is apparent that once the enzyme has penetrated into the inner layer of a granule, the layers are more readily attacked than the peripheral layers (Fuwa *et al*. 1978). The functional properties provide a set of data that gives information on the fields of application in food formulations (Hermansson 1979). Functional foods are assuming greater importance and have attracted the attention of food processors, marketers and consumers. Enzyme modified potato flour was prepared by incubating the reaction mixture containing unmodified native flour and the glucoamylase enzyme at 60°C for 90 min (Avula *et al*. 2007a).

FUNCTIONALITY OF POTATO FLOUR

Potato flour, being starch-rich, exhibits unique functional properties that determine its suitability in specific product formulations. However, the properties of potato flour may be influenced by the method of preparation, severity of heat treatment, type of modification, the presence of other com-

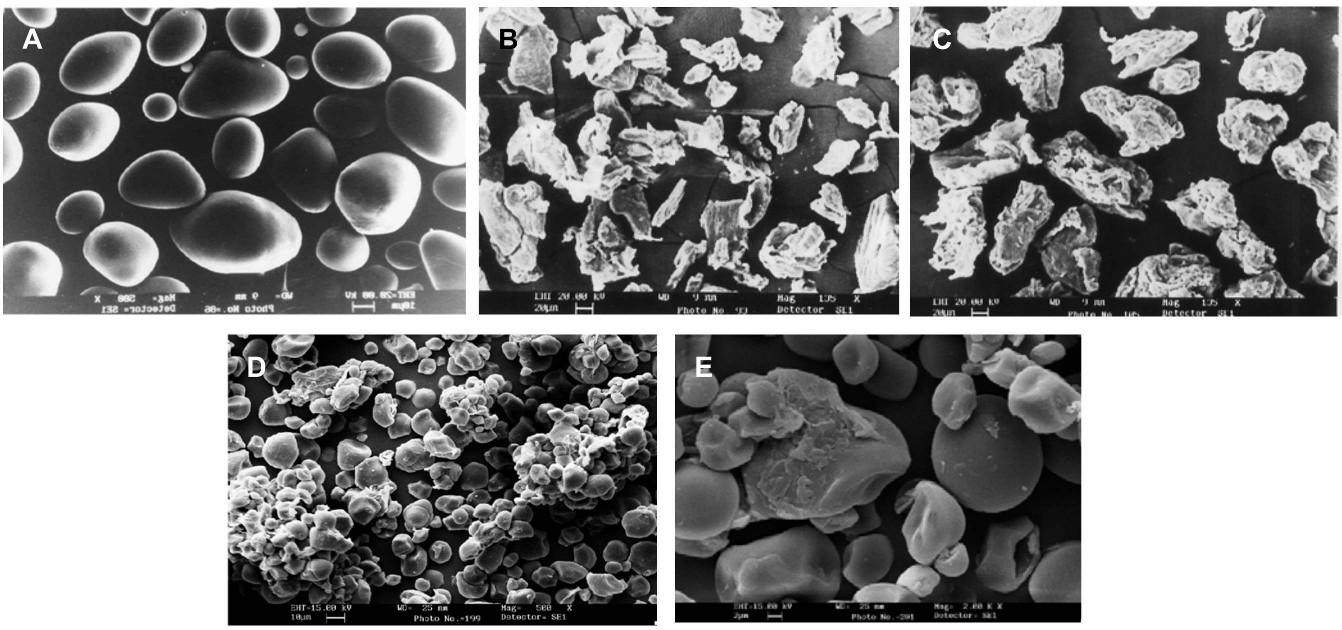

Fig. 1 SEM images of potato flours. (**A**) Native; (**B**) Drum-dried sample showing clustered granules as aggregated mass; (**C**) Hot air-dried (65°C) showing clustered granules; (**D**) Acetylated showing indentation of granules; (**E**) Enzyme (Glucoamylase) modified showing few ruptured granules. Reprinted from **Avula RY, Guha M, Tharanathan RN, Ramteke RS** (2006) Influence of drying conditions on functional properties of potato flour. *European Food Research Technology* **223**, 553-560, with kind permission of Springer Science + Business Media, ©2006. Reprinted from **Avula RY, Guha M, Tharanathan RN, Ramteke RS** (2007) Characteristics of acetylated and enzyme modified potato and sweetpotato flours. *Food Chemistry* **103**, 1119-1126, with kind permission of Elsevier, ©2007.

ponents such as fiber, protein, etc. The changes in structural characteristics of starches occurring as a result of modification or treatment may also be responsible for bringing specific functionality to the potato flour. Hence, the limited data available for functional properties of potato flour are different from those of starch since extra constituents available in flour (non- starch polysaccharides, protein, fat, etc.), restrict access of water into the starch granules. Visco-amylograph pasting parameters of sweet potato flour, were not correlated to the pasting parameters of its purified starch (van Hal 2000; Jangchud *et al*. 2003).

Granule size and morphology

Scanning electron microscopy studies of native and modified potato flour showed considerable morphological differences. Native flour (**Fig. 1A**) has oval, spherical and irregularly shaped starch granules of 6-60 μm size, whereas the granular appearance disappeared in heat treated drum dried and hot air dried flours. Agglomeration of granules was observed in heat treated flours and the size of such agglomerations was found to be more than 100 μm (**Fig. 1B, 1C**). Though the process conditions and severity of heat treatment differed, the morphological features of drum dried and hot air dried starch granules resembled each other (Avula *et al*. 2006). Exposure of internal surface and gelatinisation of starch were indicated by disruption of the granules. These changes would have improved hydration of drum dried and hot air dried flours that determined the pasting viscosities. The layered internal structure of starch granule was also conformed by the appearance of terraced or step shaped inner portion of some of the granules. In a pearl string like starch granule, pearl is the crystal and the string is amorphous. Due to heat treatment the string is disrupted and the pearl is liberated (Tamaki *et al*. 1997). Noodle quality was determined by the source and size of the starch granules (Chen *et al*. 2003).

Acetylated potato flour was prepared by allowing unmodified potato flour to react with acetic anhydride. Indentation of granules in acetylated flours, was observed as a result of modification, due to which the granules appeared as clusters (**Fig. 1D**). Introduction of hydrophilic groups to the starch molecules and subsequent increase of hydrogen bonding would have resulted in fusion of starch granules in acetylated fours (Singh *et al*. 2004). Therefore, starch molecules, coalescing together resulted in fusion of granules. The fragmentation of the granules would also have taken place during the process of indentation. The cavities observed in some granule indentations would have originated from deformation caused by other granules and/or constituents. The fragmentation and the presence of substituents in acetylated flour would have influenced the crystallinity of the starches which, in turn would have decided their altered functional properties (Avula *et al*. 2007a). Slight surface erosion of granules was observed in enzyme modified potato flour which was prepared by incubating the reaction mixture containing unmodified potato flour and glucoamylase at 60°C. Few granules of enzyme modified flour also showed surface terraces, which are exposed edges of layered internal structures (**Fig. 1E**). The enzyme penetration was not found to be significant as large proportion of starch granules of potato flour attacked by the enzyme did not show the outer striated or the inner shell structure. Thus enzyme penetration resulted in only superficial surface erosion of the granules, which might be due to poor adsorption of glucoamylase onto the granule surface.

Paste viscosities

Pasting properties of potato flour indicated the extent of molecular degradations and degree of paste viscosity and stability. The pasting curves of native and modified potato flours are given in **Fig. 2**. The native flour has shown a pasting curve, typical representative of unprocessed raw starch product with a very high peak, hot paste and cold

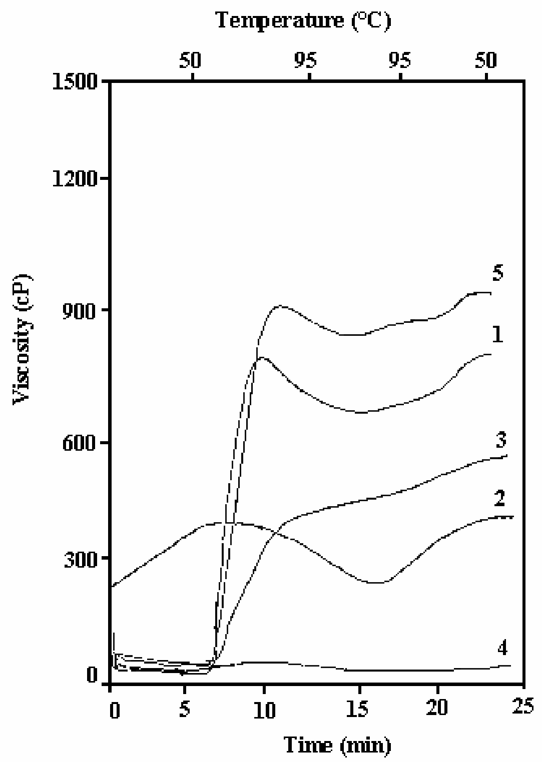

Fig. 2 Viscoamylograms showing pasting behavior of potato flours. 1) Native; 2) Drum-dried; 3) Hot air-dried; 4) Acetylated; 5) Enzyme-modified. Reprinted from **Avula RY, Guha M, Tharanathan RN, Ramteke RS** (2007) Physical properties of acetylated and enzyme-modified potato and sweetpotato flours. *Journal of Food Science* **72**, E249-E253, with kind permission of Blackwell, ©2007; Avula RY, Guha M, Tharanathan RN, Ramteke RS (unpublished data).

paste viscosities. Native potato flour showed unrestricted swelling, exhibiting maximum viscosity at a relatively shorter period of heating. A higher peak viscosity corresponds to a higher thickening power of starch. Pasting viscosities of drum dried and hot air dried flours were much less, compared to native flour as their starch granules were gelatinized and no further swelling occurred during the heating (**Fig. 2**). Reduction in viscosity is particularly important for preparation of weaning and supplementary foods (Muyonga *et al*. 2001). The hot paste viscosity (HPV) measures the tendency of the paste to breakdown during cooking, and a high value is preferred for industrial purposes (Weissenborn *et al*. 1994; Kim *et al*. 1996). The changes in breakdown values (PV- HPV) of flours reflected changes in crystallinity, swelling and extent of amylose leaching. The amylose molecules being randomly dispersed, can orient themselves in parallel fashion to form aggregates of low stability, leading to gel formation (Olkku and Rha 1978; Leelavathi *et al*. 1987). When hot starch pastes are cooled, the extent of increase in viscosity is governed by the retrogradation tendency of the starch and this behavior is determined by the affinity of hydroxyl groups of one molecule to another. A high setback value is useful in products requiring high viscosity and paste stability at low temperature and a low set back value indicates a non-cohesive nature of starch, which is useful in many industrial applications (Oduro *et al*. 2000). Since the viscosity of most commercial native starches decrease during these processes, the high stability of heat treated flours during heating and cooling processes, is useful in products requiring sterilization such as baby food (Ancona *et al*. 2003). Processed flours with low pasting viscosities become the basis for infant foods where calorie density is critical or drinks where consistency is an important acceptability consideration.

The presence of substituent functional groups caused least peak viscosity and minimized its tendency towards setback or gel formation in acetylated potato flour due to restricted swelling of starch. The viscosity values of acetylated flour obtained after isothermal holding at 95°C (hot paste viscosity) were much lower than peak viscosity values (**Fig. 2**). Esterification of starch hydroxyl groups to give acetate groups results in reduced pasting temperatures due to weakening of associative forces (Moorthy 1985). The functional groups present in chemically modified flours prevent starch chains from associating and the partial depolymerization that has occurred during the process of modification would also have resulted in low setback (Moorthy 2002; Avula *et al*. 2007a). The degree of substitution (DS) for a starch derivative is defined as the number of hydroxyl groups substituted per D-glucopyranosyl structural unit of the starch polymer. Since each D-glucose unit possesses three reactive hydroxyl groups, the maximum possible DS value is 3. Therefore, the reactions to form acetylated flour can be controlled with high accuracy by adjusting the molar ratio of the reagent and catalyst in the reaction mixture, in order to obtain the desired DS value (Wang and Wang 2001). The IR spectra provided evidence for acetylation of potato flour by the presence of the ester carbonyl group stretch at 1731 cm^{-1} (C=O) (Avula *et al.* 2007a). Enzyme modified flour showed high pasting viscosity values as the starch molecules were strengthened and resisted breakdown of paste (**Fig. 2**). Further, enzyme modified flour exhibited resistance to retrogradation as indicated by low setback value than that of native flour. Fermented maize flour exhibited higher peak viscosity than that of unfermented flour (Adeyami and Beckley 1986), and an increase in cold paste viscosity of amylase treated starch was observed by Leman *et al.* 2005. Flours with higher peak viscosities are desirable for making products such as jelly and binders. Enzyme modified flour improved the emulsifying and oil absorption capacity and it is recommended for manufacture of low fat - low sugar wafers and other bakery products (Taeuful *et al.* 1992). The low retrogradation pattern and the stability of enzyme modified flours against thermal and mechanical factors will be useful for frozen and baked products (Avula *et al*. 2007b). The high stability ratio of starch was correlated to hardness of cooked noodles (Collado and Corke 1997).

Thermal properties

The gelatinization endotherm gives an overall measure of the progressive loss of long, medium and short range order in starch granule crystallites, as they are gradually heated in excess water. The amount of heat required to gelatinize the starch is termed as enthalpy (ΔH). Gelatinization temperature (GT) is a qualitative index of the crystalline structure, whereas ΔH is a quantitative measure of the order (Marshall and Wadsworth 1993; Singh and Singh 2001). The temperature at which starch gelatinizes is given as T onset (T_o), T peak (T_p) and T conclusion (T_c). Endotherm peaks of native flour appeared between 77 – 92.6°C (**Table 2**). Higher transition temperatures indicate more stable amorphous regions and lower degree of chain branching (Biladeris 1990; Leszkowiat *et al.* 1990). Higher gelatinization enthalpy indicates more stable granular structure due to greater crystallinity (Ganga and Corke 1999). The differences in transition temperatures may be attributed to the differences in granular structure, amylose content and gelatinization temperature between the starches (Moorthy 2002). Drum dried flour and

Table 2 DSC characteristics of modified potato flours.

Potato flour	T_0	T_p	T_c	ΔH Cal / g
Native	77.0	82.0	92.6	13.7
Acetylated	69.8	80.2	90.6	4.5
Enzyme modified	76.3	80.3	93.2	19.5

hot air dried flour which were subjected to a steam pressure of 6 kg/cm^2 and 65°C, respectively during drying process did not show any gelatinization endotherm when heated up to 100°C, which confirmed the changed nature of starch granules as a result of processing. Acetylated flour showed reduced gelatinization temperature and ΔH, compared to native flour (**Table 2**). This reduction in gelatinization temperature values may be attributed to variation in degree of crystallinity and chain branching. Endotherm of enzyme modified flour showed that gelatinization temperature has not changed much but the ΔH increased after enzyme treatment (**Table 2**). It shows that the crystallinity of granules in enzyme modified flour is comparable with that of native granule even after enzyme modification. The granules are bound by protein (enzyme-starch complex) that led to stronger association of the molecules and subsequent increase in heat energy of enzyme modified flour (Avula *et al*. 2007b). The gelatinization appeared to be complete in heat treated drum dried and hot air dried flours, due to which changes in the crystallinity of their starches were imminent (Avula *et al*. 2006).

Textural profile of dough

Viscosity and consistency (parameters of fluids) are differentiated from the texture (parameter of solids) on the basis of amount of the force required to initiate flow. A typical force-distance curve represents the first and second bites. The 'pip' is an indication when every time the cross head commenced a downward stroke. The parameters that were derived from the curves include hardness, cohesiveness, springiness, gumminess, chewiness and adhesiveness (Bourne 2002). Potato flour was kneaded by adding water to make it into cylindrical dough. Potato dough prepared from enzyme modified flour exhibited more hardness followed by acetylated flour (**Table 3**). Cohesiveness values of potato dough indicate the strength of the internal bonds of potato dough that in turn determine how well the product withstands a second deformation (compression) relative to how it behaved under the first deformation. Cohesiveness of potato dough did not change significantly as a result of modifications. Intact crystalline structure of starch in enzyme modified flours as observed in SEM would have caused variation in dough hardness and cohesiveness. Springiness of potato dough was diminished in both acetylated and enzyme modified flours as their starch molecules could not establish enough junction zones of adequate size to give an elastic net work (Avula *et al*. 2007b). Potato dough prepared from modified flours showed low values of adhesiveness. Textural properties of potato dough would have been influenced by gelatinization temperature, crystallinity of starch granules in addition to processing conditions,

Table 3 Textural properties of potato dough at different moisture levels.

Characteristic	Native moisture (%)		Acetylated moisture (%)		Enzyme modified moisture (%)	
	42.5	48.5	42.5	48.5	42.5	48.5
Hardness (N)	12.1	8.1	21.8	14.2	34.9	13.9
Cohesiveness	0.09	0.08	0.08	0.09	0.07	0.09
Springiness (mm)	1.3	1.1	1.1	1.0	1.0	1.1
Adhesiveness (N)	1.9	2.6	1.7	1.2	0.6	2.1

and type of modification. The textural properties varied with change in water content (**Table 3**), thereby highlighting the importance of dough moisture in product development. Toyakawa *et al*. (1989) reported that overall acceptability of noodles were significantly correlated with cohesiveness values. Low cohesiveness of noodles may result from insufficient release of amylose due to strong internal bonds, resulting in low solubility and swelling power during cooking (Numfor *et al*. 1995, 1996). Kim *et al*. (1996) reported that cohesiveness of starch could be considered to rapidly screen samples before conducting a more laborious sensory evaluation.

Swelling and solubility

When starchy products are heated in an aqueous medium, the H-bonds holding the starch structure weaken, allowing the granules to absorb water and swell. Swelling power provides evidence of non-covalent bonding between starch molecules. Factors such as the amylose: amylopectin ratio, chain length and molecular weight distribution, degree/ length of branching and conformation determine the degree of swelling and solubility (Rickard *et al*. 1991). The bonding forces within the granules of starch affect swelling power (Adebowale *et al.* 2002). Acetylated flour exhibited the least swelling power compared to other treated flours and its swelling power raised from 60°C onwards (**Fig. 3**). Esterification of substituent groups makes the strongly bonded molecules unavailable for water to hydrate and swell. Further, presence of high amylose content, stronger intermolecular bonds, non-starch carbohydrates and other constituents in the starch, and formation of lipid-starch complexes can reduce swelling (Leach *et al*. 1959; Swinkles 1985; Eliasson and Gundmundsson 1996; van Hal 2000). Formation of a large number of crystallites would also increase granular stability, and reduce granular swelling (Hoover and Ratnayake 2002).

Drum dried potato flour exhibited higher swelling power compared to native and other treated flours (**Fig. 3**). Swelling power of differently processed potato flours indicated the changes occurred in the molecular organization within their starch granules (Avula *et al*. 2006). The suppression effect is more due to fibrous material rather than sugars present in the flour (Moorthy *et al*. 1996). In heat processed flours, swelling and solubility have improved due to the depolymerization of degraded starch. The starchy flour extracted from fermented tubers also exhibited the same trend (Moorthy *et al*. 1993). Enzyme modified flour showed reduced swelling up to 60°C, though it increased at higher temperatures, i.e., beyond 70°C (**Fig. 3**). Formation of enzyme-starch complex imparts rigidity and starch granules with strongly bonded micellar structures show high resistance to swelling (Colonna *et al*. 1976; Mariam *et al*. 1996). Lipids strongly inhibit swelling as complexes with amylose while swelling is an essentially a property of the whole amylopectin (Cheng *et al*. 1996). Highly extensible *Chapathis*, requiring less energy to rupture could be made from potato flour of low amylose and high hydration capacity (Singh *et al*. 2005).

The solubility of native and differently treated potato flours increased with increase in temperature. Drum dried flour showed higher solubility whereas the acetylated and enzyme modified flours showed the least values (**Fig. 4**). Degradation of starch during thermal treatments and macromolecular disorganization improved the water absorption and solubility values of the heat treated flours (Tan and Chinnaswamy 1993). High solubility of drum dried flour even at room temperatures makes it an ideal choice for product development. The pre-gelatinized starch is expected to exhibit high solubility in cold water than unmodified starch (Morrison 1988) and the anomalies may be due to starch retrogradation and disintegration during milling (Kaur *et al*. 2002). Changes in morphological features of starch granules may also contribute to differences in swelling power

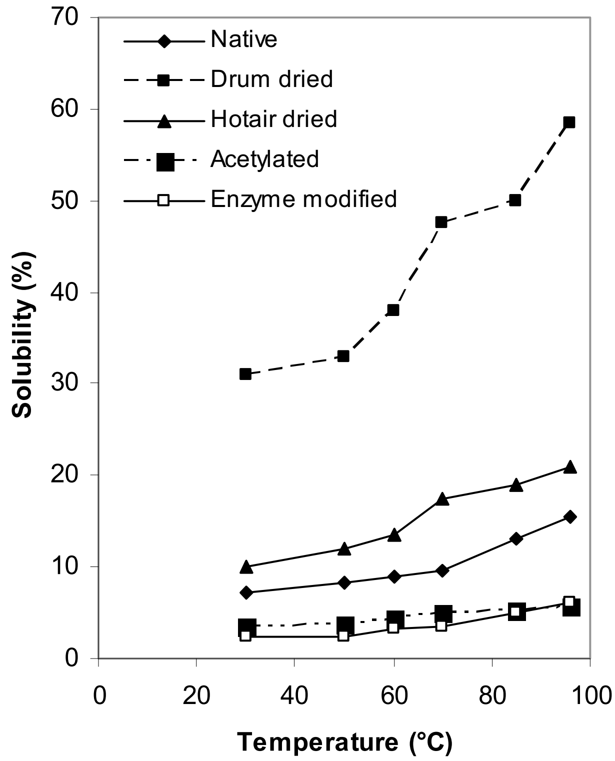

Fig. 4 Solubility of potato flours at different temperatures. Reprinted (and modified) from **Avula RY, Guha M, Tharanathan RN, Ramteke RS** (2006) Influence of drying conditions on functional properties of potato flour. *European Food Research Technology* **223**, 553-560, with kind permission of Elsevier, ©2006. Reprinted from **Avula RY, Guha M, Tharanathan RN, Ramteke RS** (2007) Characteristics of acetylated and enzyme modified potato and sweetpotato flours. *Food Chemistry* **103**, 1119-1126, with kind permission of Elsevier, ©2007.

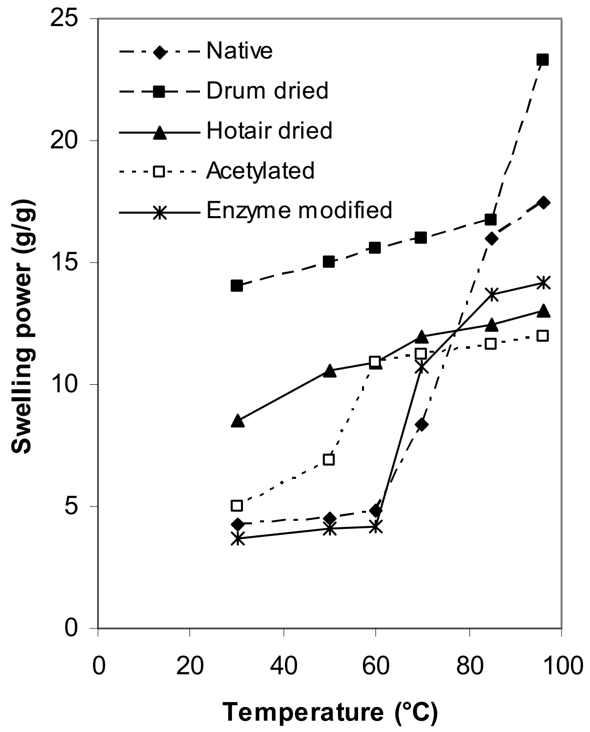

Fig. 3 Swelling behavior of potato flours at different temperatures. Reprinted (and modified) from **Avula RY, Guha M, Tharanathan RN, Ramteke RS** (2006) Influence of drying conditions on functional properties of potato flour. *European Food Research Technology* **223**, 553-560, with kind permission of Elsevier, ©2006. Reprinted from **Avula RY, Guha M, Tharanathan RN, Ramteke RS** (2007) Characteristics of acetylated and enzyme modified potato and sweetpotato flours. *Food Chemistry* **103**, 1119-1126, with kind permission of Elsevier, ©2007.

Table 4 Gel consistency and sediment volume of potato flours.

Potato flour	Gel consistency (mm)	Sediment volume (ml)
Native	25.0 ± 0.5	7.0 ± 0.2
Drum dried	145.0 ± 1.1	28.3 ± 0.3
Hot air dried	82.6 ± 0.6	12.6 ± 0.2
Acetylated	10.0 ± 0.3	5.5 ± 0.2
Enzyme modified	15.0 ± 0.3	6.5 ± 0.1

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and solubility (Adebowale *et al.* 2002). Thus suitability of modified flours in specific product formulations could be determined based on the variation in their swelling and solubility patterns.

Sediment volume

Guha *et al.* (1997) reported that sediment volume of processed starchy products is an index of starch gelatinization. Sediment volume of differently treated potato flours showed a clear gradation in gelatinization of their starch (**Table 4**). The sediment volume of drum dried flour exhibited higher values followed by hot air dried flour (**Table 4**), indicating their high degree of gelatinization. The sedimentation data thus provides a clear and useful distinction between various precooked products. The lower values of sediment volume of acetylated and enzyme modified flours was due to the presence of substituent groups and formation of enzyme-starch complex, respectively as a result of modification (Avula *et al.* 2007a).

Gel consistency

The consistency of a flour paste in 0.2 N KOH is complimentary for amylose content. The gel consistency values of differently treated potato flours were inversely correlated with viscoamylograph cold paste viscosity, excepting acetylated flour (Avula *et al.* 2007b). Drum dried and hot air dried potato flours showed significantly higher gel consistency values than enzyme modified and acetylated potato flours (**Table 4**). The higher gel consistency values of the former may be attributed to their starch gelatinization. The values of gel consistency of potato flours were correlated with their swelling and solubility patterns (Avula *et al.* 2006, 2007a). Mobility of rice flour gel increased upon parboiling, and also with increasing severity of parboiling. Gel mobility was proportional to the hydration power, sediment volume of an aqueous flour dispersion, and also related to the degree of starch gelatinization, unaffected by starch reassociation (Unnikrishnan and Bhattacharya 1988). Avula *et al.* (2007a) reported that due to the combined effect of amylose content and the molecular properties of amylose and amylopectin, the low gel consistency values of acetylated (with lowest cold paste viscosity) and enzyme modified flours (with highest cold paste viscosity) were observed. Potato flour with high gel consistency values could be useful in the development of products such as specialty dietetic foods in which higher solid content per unit volume is required.

In-vitro digestibility

Several studies have shown that uncooked native starches are less susceptible to amylolysis (Sugimoto *et al.* 1980) and digestibility is significantly improved by cooking, with either dry or moist heat or fine grinding (Dreher *et al.* 1982). Although cooking improved digestibility, a wide variation in digestibility could be observed depending on cooking conditions. Hallendoorn *et al.* (1970) compared the *in-vitro* digestibility of starch in processed mashed potato products

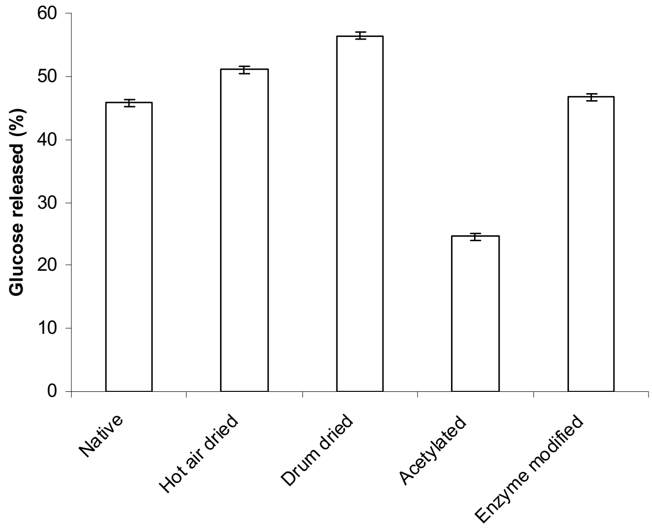

Fig. 5 Glucose (%) released by the action of glucoamylase in potato flours. Reprinted (and modified) from **Avula RY, Guha M, Tharanathan RN, Ramteke RS** (2007) Characteristics of acetylated and enzyme modified potato and sweetpotato flours. *Food Chemistry* **103**, 1119-1126, with kind permission of Elsevier, ©2007; Avula RY, Guha M, Tharanathan RN, Ramteke RS (unpublished data).

and concluded that potato flakes are more digestible than potato granules. When gelatinized potato flour was incubated with glucoamylase and analysed for released glucose, heat processed drum dried and hot air dried flours showed better *in vitro* digestibility than acetylated and enzyme modified potato flours due to the rupture and disintegration of their compact crystalline starch granular structures (**Fig. 5**). Digestibility of drum dried flour was significantly higher than other modified flours, as the disrupted state of starch granules of drum dried flour would have helped in better penetration of enzyme to facilitate digestion (Avula *et al.* 2006). Madhusudhan *et al.* (1996) found that the higher digestibility of processed flours was due to comparatively less branching and low molecular weight of the constituent fractions. Hale (1973) and Rao (1969) reported that the degree of amylolysis is dependent on the chemical nature of starch, type of processing, possible presence of inhibitors, and physical distribution of starch in relation to other dietary components such as cellulose, hemicelluloses, and lignin. Presence of substituent groups were shown to influence digestibility of modified wheat starches, and the degree of substitution (DS) on digestibility was inverse. Sharp reduction in digestibility of acetylated starches was observed by Wootton and Chaudry (1979).

Starch susceptibility to enzyme digestion is influenced not only by the plant source, but also by the processing and storage conditions. The changes in morphological features have also facilitated better digestibility in enzyme modified flour (Avula *et al.* 2007a). Determination and establishment of differences in starch digestibility of differently treated potato flours is essential in recommending for suitable application in product development. The formulation of soup mix, based on heat processed potato flour resulted in acceptable consistency with reduced pasting viscosities (Rekha *et al.* 2009). Potato flour with poor digestibility functions like dietary fiber and shows therapeutic benefits such as control of weight in obese people or blood glucose in diabetics (Skrabanja et al. 1999). Restricted digestion of starch is critical for infants, senior citizens having reduced digestive capacity and people with physical exhaustion, emotional stress or medical disorders leading to disturbed digestion (Niba 2003).

CONCLUSIONS

The high stability of drum dried and hot air dried flours during heating and cooling processes, demonstrates their possible use in products requiring sterilization such as baby food. Potato flour showing low paste viscosities (physically treated and acetylated flours) may be used in formulations requiring high solids per unit volume. Enzyme modified flour with high paste viscosities act as good thickeners. The application of modified flours would also ensure desirable levels of digestible starch in food products. Furthermore, the information on functional properties can be used in designing food processing protocols that target consumer requirements, such as for diabetics and obese people who will potentially benefit from lower levels of digestibility.

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