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The Properties of Potato Protein

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ABSTRACT

About 75% of proteins present in potato (*Solanum tuberosum*) tubers are soluble in water or salt solutions (including 50% of protein fractions of molecular weight within 44 000-45 000 Da). The pH of these proteins, mainly tuberin or patatin, is usually low. They are reserve proteins, typical of potatoes, mainly glycoproteids, which can be easy precipitated in acids at pH 3-4. Low pH (≈ 5), depending on temperature, may cause irreversible destruction of tertiary structures and precipitation of tuberin proteins. On the other hand, when the pH is slightly acidic, solubility of the majority of potato proteins is dependent on ionic strength and temperature. Data in the literature show that surface properties of potato protein fractions may vary and that these differences can be significant. The results of these studies show that most fractions exhibit emulsifying properties, while tuberin is primarily responsible for foaming. Potato proteins, except prolamines, are of great biological and nutritional value. Extensive studies have been carried out on production methods for protein preparations from potato juice. The aim of these studies was to obtain potato proteins that exhibit functional properties that could be suitable for use in food product manufacturing.

Keywords: compositional characteristics, functional properties, methods of isolation, nutritive value, potato protein

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COMPOSITIONAL CHARACTERISTICS

Protein present in potato tubers consists of several fractions varying in structure, molecular weight, physicochemical and biological properties. Globular proteins account for about 75-85% of proteins present in potatoes, while the remaining 25% is made up of insoluble protein fractions present in the cell walls of potato flesh and juice (in crystalline form), also containing trace amounts (5-10%) of RNA and iron ions (Seibles 1979; Burton 1989).

Soluble fractions depend on solubility

Soluble fractions of potato proteins were studied as early as the 19th century. In 1896 Osborne and Campbell were the first researchers to use the term 'tuberine' (cited after Desborough 1985) for potato fractions soluble in water and salt solutions, exclusively typical of potatoes (Seibles 1979; Racusen and Foote 1980; Lindner *et al*. 1980/81; Desborough 1985; Ahlden and Trägårdh 1992; Pots *et al*. 1998, 1999). Racusen *et al*. (1980, 1984) used the term '*patatin*' from Spanish '*patata*'. Proteins constituting tuberine ('*patatin*') are also referred to as reserve proteins whose major fractions are albumin and globulin (**Fig. 1**).

Seibles (1979) found that soluble fractions of potato protein contained about 75% albumin and 25% globulin. Depending on the solubility of potato protein fractions in water, salt solutions, alcohol and dilute alkali, they are referred to as albumin (*c.* 50% of total nitrogen) soluble in water and in dilute salt solutions, globulin (25-26%) soluble in dilute salt solutions, prolamin (2-4%) soluble in aqueous alcohol and glutelin (*c*. 9%) in dilute alkali. The remaining

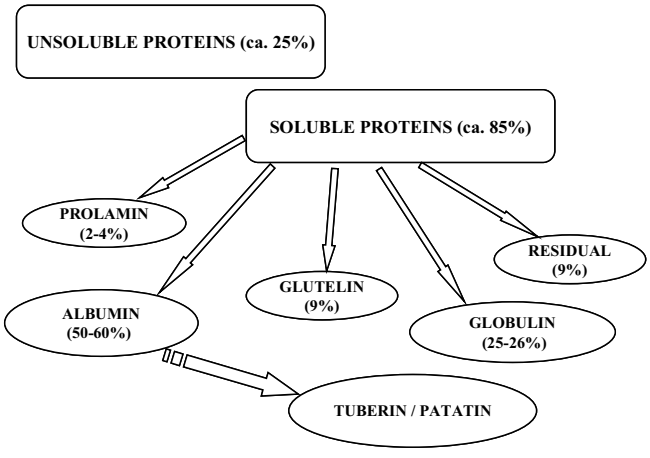

Fig. 1 Composition of potato protein. Based on Kapoor *et al.* (1975); Ahlden and Trägårdh (1992) and Ralet and Gueguen (2000).

Received: 18 July, 2008. Accepted: 18 December, 2008.

Invited Review

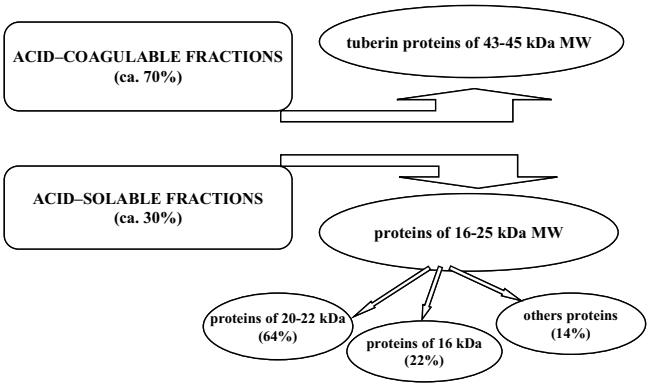

Fig. 2 Composition of acid-coagulable and acid-soluble fractions of potato protein. Based on Lindner *et al.* (1980/81), Ralet and Gueguen (2000) and van Koningsveld *et al.* (2001).

protein fractions expressed as a residual protein (*c*. 9%) are also called skeleton protein (Levitt 1950). This is found in potatoes and probably also in some non-proto-plasmic protein crystals and consists of proteins that differ in their properties and solubility (Kapoor *et al*. 1975; Knorr 1978, 1980a; Lindner *et al.* 1980/81).

Many authors (Levitt 1950; Seibles 1979; Ralet and Gueguen 2000; van Koningsveld *et al.* 2001; Ralet and Gueguen 2001) classified protein fractions that dissolved in potato juice into either soluble or insoluble in water or acids. Levit (1950) reported that the quantity of potato proteins, both soluble and insoluble in water, was almost the same and that about 68% of albumin soluble in water was also soluble in acids and that only 32% of protein fractions were insoluble in acids. Similarly, Lindner *et al.* (1980/81) separated and described protein fractions that were soluble or insoluble in acid. They also divided potato protein fractions into two groups according to their molecular weight (MW): group 1 of low MW (<27.000) and soluble at pH = 3 and group 2 of high MW (32.000-87.000) that precipitated at low pH. According to these authors, the classification of potato proteins as either acid-coagulable or acid-soluble was very useful because of their different nutritional values and functional properties as well as the practical applications of these characteristics in the food industry.

In later years, Ralet and Gueguen (1999, 2000, 2001) and van Koningsveld *et al*. (2001) reported that about 67% of proteins insoluble in acids was made up of tuberine of MW of *c*. 44 kDa. In addition, they confirmed that these proteins were glycoproteids, mostly acidic. They also studied 20-25-kDa protein fractions and found that these were basic proteins soluble in acids, 64% of which were 20-25 kDa, and about 22% of them 16 kDa peptides (**Fig. 2**). The majority of 16-25 kDa fractions are protease inhibitors, as discovered by several authors, including Pots *et al.* (1999), who found that some portions of soluble potato proteins of 5.000-25.000 Da were protease inhibitors. Some of them, e.g. chymotrypsin inhibitor, being a heterogeneous mixture of isoinhibitors exhibiting specific biochemical properties, are extremely resistant to high temperatures and maintain their activity even when heated to 100°C (Chrzanowska and Leszczyński 1977; Leszczyński 1994, 2000; van Koningsveld *et al.* 2001). The inhibitors present in potatoes in high quantities are classified into 3 groups: group I – specifically trypsin; group II – trypsin and chymotrypsin; group III – protease inhibitors, e.g. serine protease inhibitors.

High thermostability of protease inhibitors in potato tubers protects them from inactivation during processing operations. Besides, they are non-degradable and inactivated by pepsin, and for this reason, they maintain their anti-proteolytic activity in the alimentary tract (Chrzanowska and Leszczyński 1977).

Soluble fractions depend on size

Isolation of protein fractions from potato tubers, based on variations in their solubility, did not prove to be the right method for obtaining homologous proteins based on MW and properties. On the other hand, the use of separation techniques proved to be effective in the isolation and separation of protein fractions exhibiting unique properties and varying in MW. Particularly effective were FPLC (fast-protein liquid chromatography) and sodium dodecylsulphate-polyacrylamide gel electrophoresis, i.e. SDS-PAGE (polyacrylamide gel electrophoresis). Many authors used chromatographic and electrophoretic techniques (Ohms 1979; Grison 1980; Shomer *et al.* 1982; Park 1983; Park *et al.* 1985; Reda *et al.* 1989; Hannapel 1991; Ahlden and Trägårdh 1992) to determine the composition of protein fractions in different potato cultivars. Racusen and Foote (1980) found that glycoproteins of MW of about 40.000 Da (possessing sugar residues) were a major group of soluble protein fractions in potato tubers. Other authors (Racusen and Weller 1984; Ahlden and Trägårdh 1992; Pots *et al.* 1999) reported that the majority of protein fractions in potato tubers do not occur as subunits, but as polypeptides intermolecularly crosslinked by disulphide bonds in the aggregates composed of two, four or more molecules, the MW of which is found within the ranges of 14.000, 17.000-22.000, 35.000-44.000, 45.000 and 80.000 Da without the exception for the potato varieties and growing season (Ahlden and Trägårdh 1992). Tuberine, a major protein fraction present in potato tubers is built up of 88.000 Da dimers, i.e. a combination of two cross-linked protein molecules, each with a MW of 44.000 Da (Racusen and Weller 1984). The sizes of potato protein aggregates can be even larger, e.g. the molecular weight of potato phosphorylase is 320.000 Da (Snyder and Desborough 1978; Seibles 1979; Burton 1989).

IEF (isoelectric focusing) was used to separate protein fractions on a pH gradient (Seibles 1979; Racusen and Foote 1980; Lindner *et al.* 1980/81; Liedl *et al.* 1987; Ahlden and Trägårdh 1992). The results showed that most of the protein of 44 000 (dominant), 55 000 and 66 000 show a number protein bands with isoelectric point in the acidic range between pH 5.0 and pH 5.5. The same fractions were described by Ralet and Gueguen (2000) as acid fractions contained mainly patatin (67%). Besides, it was found that the fractions separated isoelectrically at pH values of approximately 6.0, 6.5, 7.2 and 7.8 consisted mainly of two protein fractions with molecular weight close to 20 kDa and one at a 14 kDa. These fractions were defined as basic fractions contained the 20-25 kDa proteins family and a 16 kDa polypeptide, probably corresponding to the protease inhibitor (Ralet and Gueguen 2000). Focusing (IEF) electrophoresis was used to identify and categorize new potato cultivars. Protease inhibitors present in potato tubers can appear as groups of isoinhibitors and their separation is associated with the whole protein complex separation, specific for each potato variety. For this reason, they are the object of many breeding studies (Chrzanowska and Leszczyński 1977; Ryan and Pearce 1978; Burton 1989).

THE EFFECTS OF PH, IONIC STRENGTH AND HEAT TREATMENT

In recent years, researchers in many countries worldwide have directed a lot of attention to and carried out studies on the effects of thermal treatment of potato protein fractions in low NaCl solutions – at low concentrations (<200 mM) – on the structure and solubility of various protein fractions and their functional properties (Ralet and Gueguen 2000, 2001; van Koningsveld *et al.* 2001). The data obtained in these studies show that solubility of potato proteins at pH >5 is closely correlated with the ionic strength of the solution and the presence of unfolded tuberine.

The addition of NaCl to a colloidal protein solution increases its ionic strength, which depends not only on the electrovalence, but also on the electrolyte concentration.

Table 1 Solubility of the main fractions of potato protein in dependence on ionic strength, pH and temperature (Ralet and Gueguen 2000; van Koningsveld *et al.* 2001; Ralet and Gueguen 2001).

Fraction	pH protein solution	Ionic strength of salt in solution [mM/dm^3]	Temperature [°C]			
			20	40	60	80
Tuberin/patatin	4	15	+*	+	+	+
	4	200	-*	+	+	+
	7	15	-	-	-	-
	7	200	-	-	+/-	+
Proteins of 16-25 kDa	4	15	-	-	-	-
	4	200	-	-	+/-	+
	7	15	-	-	-	+
	7	200	-	-	-	+

When the ionic strength of a slightly acidic or neutral potato protein solution is increased, the destructive effects of high temperatures on the protein are significantly reduced. By increasing ionic strength of the solution to 0.2 M/dm^3, denaturation temperatures of the majority of potato protein fractions also increase and destruction of the secondary structure of proteins occurs prior to complete denaturation (**Table 1**). However, precipitation of tuberine at pH 5 results in irreversible changes in the tertiary protein structure. This in turn may have an impact on digestibility of proteins and their functional properties, such as: solubility, emulsifying capacity, foam formation and water holding capacity (WHC), very important in food processing industries. According to van Koningsveld *et al.* (2001) and Ralet and Gueguen (2000) temperature as low as 70°C along with appropriate ionic strength of the protein are able to precipitate the majority of potato proteins and inactivate about 80% of protease inhibitors.

Some authors (Ralet and Gueguen 2000, 2001; Deveaux-Gobert 2008) report that tuberine and 16-25 kDa potato fractions exhibit unique functional properties, such as foam forming and emulsifying capacity, which vary, depending on the pH and ionic strength. Undenaturated (native) potato protein, especially 44 kDa patatin (tuberine) shows very good foaming properties. This is comparable to egg white at pH ranges from 5 to7, irrespective of the ionic strength of the solution. This is in contrast to 16-25 kDa protein fractions. Tuberine is able to form thick foam of great volume and stability unlike 16-25 kDa protein fractions. Whatever the pH or ionic strength, the 16-25 kDa fraction is a very poor foaming agent. However, the stability of foam formed by 16-25 kDa protein fractions is enhanced at a pH range of 4 to 5 when 1% NaCl is added to the protein solution. Besides, patatin and 16-25 kDa fractions show significant differences in their oil emulsification capacity. The stability of emulsions formed by tuberine (patatin) is low, but it improves at pH 4. At low pH, tuberine-containing solutions form creamy emulsions of high water content, showing relatively high resistance to coalescence, especially after heating. The same authors (Ralet and Gueguen 2000, 2001) also reported that in contrast to tuberine, unheated 16-25 kDa potato fractions form emulsions exhibiting high stability, irrespective of the pH and ionic strength of the solution. After heating, the emulsions are less stable and prone to coalescence.

BIOLOGICAL AND NUTRITIVE VALUE

Potato protein is of great biological and nutritional value (Kapoor *et al*. 1975; Meister and Thompson 1976; Knorr 1978; Burton 1989; Lisińska and Leszczyński 1989; Eppendorfer and Eggum 1994; Ralet and Gueguen 1999; Leszczyński 1994, 2000), comparable with egg white. The biological value is mainly dependent on the amino acid composition. **Table 2** shows that the biological value of potato protein fractions, except prolamines present in potato tubers in trace amounts, is comparable to the FAO egg standard of essential amino acids (Kapoor *et al.* 1975; Rexen 1976; Knorr 1978; Desborough 1985; Lisińska and Leszczyński 1989; Eppendorfer and Eggum 1994). Potato protein contains large amounts of amino acids asparginic and glutaminic acids, lysine and leucine. Due to their high lysine content, potato proteins can be a good supplement of cereal products, low in this amino acid.

The nutritional value of proteins is determined with regard to chemical score (CS), essential amino acid index (EAAI), protein efficiency ratio (PER), biological value (BV) and net protein utilization (NPU) (Rakowska *et al.* 1978; Desborough 1985; Friedman 1996; Rakowska and Ochodzki 2001; Pisulewski and Pysz 2002; Gawęcki 2003; Pysz and Pisulewski 2004). A comparison of various plant and animal proteins (**Table 3**) shows that the biological value of potato protein is higher than that of other crops, e.g. pea, wheat or rice (Kapoor *et al.* 1975; Rakowska *et al.* 1978; Desborough 1985; Lisińska and Leszczyński 1989; Eppendorfer and Eggum 1994) and comparable with the biological value of animal proteins. The PER of potato protein determined in various cultivars was found within the range from 0.95 to 2.3 (1.7 on average) and was slightly lower than the PER of milk protein (2.5-2.9), similar to the PER of beef and poultry meet (2.1-2.5), but higher than the PER of rice (1.76), wheat (0.77) and soy (1.3-2.3). The CS of potato protein ranges from 57 to 69, EAA Index from 49 to 83, BV from 77 to 79 and NPU from 60 to 73. These values confirm the high nutritional value of potato, which can be enhanced when supplemented with other proteins, e.g.

Table 2 Essential amino-acids contents [mg·g^{-1}N] in potato in comparison to suggested human requirements (Kapoor *et. al* 1975; Knorr 1978; Boutrif 1991; Schaafsma 2000; Gawęcki 2003).

Amino-acid	Potato protein	Potato protein fraction					Egg protein	FAO standard/ 1991
		Albumin	Globulin	Prolamine	Gluteline	Residual		
Methionine	120-260*	131	121	87	128	148	214	346*
Lysine	424-441	471	525	284	483	352	448	403
Tryptophan	84	95	124	49	84	83	93	100
Isoleucine	261-325	283	311	174	279	316	423	415
Leucine	499-533	502	514	249	563	474	490	553
Phenylalanine	231-370**	424	334	181	368	308	362	627**
Threonine	204-304	305	256	244	283	298	325	317
Valine	293-390	265	348	284	338	352	463	454
Histidine	92-132	129	170	64	160	191	150	-
Arginine	271-296	323	291	206	307	326	419	-

*Methionine + cysteine, ** Phenylalanine + tyrosine

Table 3 The nutritive value of potato protein in comparison to chosen plant and animal origin proteins (Kapoor *et al.* 1975; Desborough 1985; Lisińska and Leszczyński 1989; Schaafsma 2000; Pęksa 2006).

Quality index	Potato protein	Soy protein	Wheat protein	Rice protein	Caseine	Beef	Poultry
CS	57-69	42-48	30-49	47	54	69	59-63
EAA	48-83	71	64	79	80	80	72-78
BV	65-94	64-80	66	80	80	70-75	77
PER	0.95-2.3	1.3-2.3	0.77	1.76	2.5-2.9	2.1-2.5	2.1-2.5
NPU	60-73	61-64	45-51	-	67-72	68-79	68-77

Table 4 The requirements regarding protein preparations for food purposes.

Requirement	Composition/Property	References
Chemical composition	Total solids, nitrogen compounds, protein, sugars, carbohydrates, fat, ash, minerals	Knoor *et al.* 1977; Knoor 1978, 1979, 1980; Rutkowski and Kozłowska 1981; Sikorski 2001
Nutritional quality	Amino-acid composition of protein preparations or particular protein fractions, indexes of the nutritive value	Kapoor *et al.* 1975; Knoor 1978, 1979; Rutkowski and Kozłowska 1981; Rakowska and Ochodzki 2001; Gawęcki 2003
Functional properties	Solubility, emulsification, foaming, fat absorption capacity, water holding capacity, water binding capacity, colour, flavour	Knoor *et al.* 1977; Kinsella 1976; Holm and Eriksen 1980; Knoor 1980a, 1980b; Kinsella 1981; Rutkowski and Kozłowska 1981; Knoor 1982; Jackman and Yada 1988; Zayas 1997; Sikorski 2001; Świderski 2003

Table 5 Factors affecting chosen functional properties of patatin and 5-25 kDa potato proteins families.

Functional property	Factor	References
Solubility	pH, thermal treatment, ionic strength	Ralet and Gueguen 2000; Van Koningsveld *et al.* 2001
	pH, thermal treatment	Jackman and Yada 1988
	pH, carboxymethylcellulose	Vikelouda and Kiosseoglou 2004
	pH, carboxymethylcellulose, heat treatment, ionic strength	Partsia and Kiosseoglou 2001
Emulsification properties	pH, thermal treatment, ionic strength	Ralet and Gueguen 2000
	pH, thermal treatment	Jackman and Yada 1988
	pH, carboxymethylcellulose	Vickelouda and Kiosseoglou 2004
Foaming properties	pH, thermal treatment, ionic strength	Kinsella 1981
	pH, thermal treatment	Jacman and Yada 1988
	pH, carboxymethylcellulose, heat treatment, ionic strength	Partsia and Kiosseoglou 2001

whole egg (Kapoor *et al.* 1975; Rexen 1976; Rakowska *et al.* 1978; Knorr 1978; Lisińska and Leszczyński 1989; Eppendorfer and Eggum 1994).

It is known that the CS should be determined with respect to a dietary preschool age (for 2-5 year-old children) standards of indispensable amino acids and according to the FAO/WHO requirements from 1991, also the protein digestibility-corrected amino acid score (PDCAAS) should be taken into account, including the nutritional value of protein depending on the content of limiting amino acid (CS) and real digestibility of protein, determined either *in vivo* or *in vitro* (Boutrif 1991; Friedman 1996; Sarwar 1997; Schaafsma 2000; Rakowska and Ochodzki 2001; Pisulewski and Pysz 2002; Pysz and Pisulewski 2004). Pęksa (2006) studied potato proteins obtained during thermal coagulation at 70°C with the use of NaCl and $CaCl_2$ and found that their PDCAAS was very high (within a range of 70-99) and approximated the PDCAAS reported for proteins present in beef, soy isolates and whole egg.

The nutritional value of proteins depends on where they originate from as well as on technological processes and protein interactions with other dietary components. Digestibility of proteins can be drastically reduced by the pH, temperature, moisture content, oxidants and also protein-fat, protein-carbohydrate and protein-protein interactions (Giese 1994; Friedman 1996).

The studies on varietals differences between potato tubers used for various purposes, among others, for starch production (Rexen 1976) showed that the nutritional value of starchy potatoes was better than that of other cultivars, which may be important in potato juice applications for potato protein preparations made by starch plants.

FUNCTIONAL PROPERTIES OF PREPARATIONS FOR FOOD PURPOSES

Potato preparations used as food products supplementation must fulfill certain requirements regarding their chemical composition, nutritional value and functional properties, i.e. physicochemical properties affecting the quality and sensory properties of food products destined for consumption, processing and storage (**Table 4**). According to the authors cited in **Table 4**, functional properties are a major criterion determining the usability of proteins originating from various sources. However, determination and comparison of the functional properties of proteins is very difficult due to a wide variety of methods used for protein isolation and stability as well as quality assessment of subsequent products. However, due to the fact that proteins originate from a variety of sources and the methods used for their assessment vary, it is difficult to lay down a common method for determination and comparison of their functional properties. The data reported by many authors (**Table 5**) show that functional properties (solubility, emulsification and foaming) of potato protein fractions which differ in their MW depend on protein denaturation. The most important functional properties are related to protein-water interactions, i.e., water binding capacity (WBC), water holding capacity, swelling, solubility, emulsifying capacity, viscosity, gelation and syneresis. Water holding capacity is a critical factor determining the functional properties of proteins, as it affects texture and other sensory properties of food products.

Due to denaturation, polypeptide chains are unfolded and next restructured, which may reduce the availability of polar functional groups of amino acids, and consequently water holding capacity (Zayas 1997; Sikorski 2001). Drastic conditions of coagulation, in particular long-term high temperature (>90°C) effects can result in irreversible structural changes in proteins and reduce their activity to develop functional properties in food products (Kinsella 1976; Knorr 1978, 1980b; Jackman and Yada 1988; Zayas 1997; van Koningsveld *et al.* 2001; Milewski 2001).

Oil absorption of proteins and protein-fat interactions in emulsions affect texture and other qualitative features of ready-made food products. According to Kinsella (1976, 1981) and Sathe *et al.* (1982), the mechanism of oil absorption is connected with its physical binding, whereas oil absorption of vegetable-originating protein preparations de-

pends on protein concentration, molecule sizes and porosity, availability of hydrophobic amino acids and protein-fat-carbohydrate interactions. In general, protein products containing denaturated protein of low solubility, exhibit high oil absorption.

Protein activity on air/water or oil/water phase borders is a major factor affecting foams and emulsions, their formation and stability (Kinsella 1976, 1980; Jackman and Yada 1988; Zayas 1997; Ralet and Gueguen 2000; Partsia and Kiosseoglou 2001; Sikorski 2001). Foam-forming proteins reduce the interfacial tension between air and liquid, thereby increasing the viscosity and elasticity of the liquid phase, resulting in the development of a firm film. High stability of foams is due to the contribution of high MW globular proteins, while high-volume foams are formed by more mobile proteins of lower MW, at a pH approximate to the isoelectric point. Potato protein preparations can be used as foam-forming substances provided that they fulfill the solubility criteria.

In molecular aspect, the functionality of proteins in food products depends on protein structure, conformation and their ability to interact with fats, carbohydrates, other proteins, ions, water and substances enhancing flavour and aroma of foods (Kinsella 1976; Ralet and Gueguen 1999, 2000; Vikelouda and Kiosseoglou 2004). For example, gelling properties of soy are due to disulfide linkages. Conformation and amino acid composition of the whole egg are major factors responsible for its excellent foam-forming properties (Zayas 1997; Sikorski 2001). In turn, good hydration of potato proteins are likely due to the presence of charged and polar groups of amino acids on the surface of protein molecules, especially lysine, and glutamic and aspargic acids, which exhibit a high water-binding capacity.

METHODS OF POTATO PROTEIN ISOLATION

In most starch plants, also being protein producers, protein coagulation occurs at high liquid temperature (90°C) and when pH is reduced to ~4-5, for about 30 minutes. Under these conditions, both the yield and purity of the resultant protein are high, but so is its degree of denaturation, which affects rehydration of the products after drying as well as other functional properties, such as foamability or emulsification (Sroczyński 1961; Knorr *et al.* 1977; Wojnowska *et al.* 1979; Knoor 1982; Jackman and Yada 1988; van Koningsveld *et al.* 2001). Dry matter of dry potato protein produced on an industrial scale for animal feed contains a minimum of 80% protein and only 2% of ash compounds. Since its digestibility is good, it is used as an ingredient of concentrates and as a milk substitute in foodstuffs for calves (Kapoor *et al.* 1975; Knorr 1978; Deveaux-Gobert 2008). Due to negative functional properties (low water absorption and solubility in water) of protein obtained in this manner, it can by no means be destined for food processing industries.

The methods used for protein recovery from potato juice and the quality of subsequent products were extensively studied in the 1970s and 1980s. Potato proteins were isolated on a laboratory scale, using both thermal coagulation at varying pH ranges (both high and low) and coagulation at room temperature at varying pH ranges in the presence of HCl, H_2SO_4, $FeCl_3$, $Al_2(SO_4)_3$, citric acid (Meister and Thompson 1976; Knoor 1980a, 1982) and $(NH_4)_2SO_4$ (Kapoor *et al.* 1975; van Koningsveld *et al.* 2001). In recently used methods, the concentration of potato proteins is obtained with the use of polyelectrolytes such as CMC-carboxymethylcellulose, bentonite and polyacrylamide coagulants (Wojnowska *et al.* 1979, 1981; Lindner *et al.* 1980/1981; Baraniak *et al.* 2004; Vikelouda and Kiosseoglou 2004). Besides, thermal coagulation with the use of $CaCl_2$ has been used (Pęksa 2006) as well as membrane techniques such as ultrafiltration by membranes retaining substances of appropriate MW (e.g. 6000 Da) in combination with reverse osmosis, dialysis by membranes retaining substances of MW >12.000 Da (e.g. against distilled water, phosphate buffer and salt solutions varying in ionic strength) and by chromatography (Seibles 1979; van Koningsveld *et al.* 2001; Zwijnenberg *et al.* 2002). Isolation of some potato protein fractions by membrane techniques or chromatography has proved to be suitable for the production of potato preparations exhibiting good functional properties, useful in the food industry to be used as emulsion stabilizers and as substances binding water and oil (Ralet and Gueguen 1999, 2000, 2001; Witrowa-Rajchert 2001; Zwijnenberg *et al.* 2002; Vikelouda and Kiosseoglou 2004).

The functional properties of potato protein obtained by many researchers (Sroczyński 1961; Meister and Thompson 1976; Knoor 1977, 1978, 1979, 1980a, 1980b; Wojnowska *et al.* 1981; Jackman and Yada 1988; Løkra *et al.* 2008) in the form of dehydrated concentrates containing about 76-80% of crude protein were closely correlated with the methods used for protein coagulation and drying of the product. Knoor (1980b) found that protein coagulants obtained at low pH (3-5) and 98°C exhibited lower oil absorption and ash content, higher protein content and reduced solubility of nitrogenous compounds as compared to the concentrates obtained from coagulation performed at room temperature. The protein preparations obtained at room temperature, especially those obtained in the presence of heavy metals ($Al_2(SO_4)_3$ and $FeCl_3$) or citric acid exhibited good solubility (40-80%) of nitrogenous compounds, but too high (20-38%) content of ash. According to Knoor (1980a, 1980b), a method used for protein coagulation does not have a significant impact on foaming of the subsequent protein preparations. However, a significant influence of the pH and the coagulation method on water absorption of potato protein concentrations was observed. Knoor (1979) studied the effects of drying methods on the quality of potato protein concentrates and found that the best quality, regarding both amino acid composition and functional properties, including sensory characteristics, were obtained by the freeze-drying method. These statements confirm Løkra *et al.*'s (2008) studies. Knoor (1979) in his experiment used potato protein concentrates for bread dough and found that when they were alternately used with wheat flour in amounts not exceeding 10%, they improved the rheological properties and shelf-life of the bread, with no unprofitable effect on the sensory properties. Sroczyński (1961) studied the effects of pH and temperature on protein coagulation in potato juice and found that increasing pH also increased the initial temperature of protein coagulation from about 19°C at pH 5 to about 98°C at pH 9. He also found that the yield of protein recovery from potato juice using thermal coagulation was higher than when acid was used. Besides, he observed that the yield of coagulation only increased to 80°C. He dried wet protein in a vacuum drier and found that drying temperatures (50 and 80°C) markedly influenced the colour and flavour of the preparations. Protein dried at lower temperature (50°C) was lighter (light grey) in colour and it was free of the burn taste. Wojnowska *et al.* (1979) obtained potato protein preparations from potato juice by ultrafiltration and thermal coagulation at 95°C. They found that concentration ratios (1:5, 1:10 and 1:15) affected total protein content of dry matter of the preparation (ranging from 54 to 79%) as well as functional properties, including solubility, water absorption, wet ability and emulsifying and foam-forming abilities. Wojnowska *et al.* (1981) suggested that the concentrates they obtained could find applications in the baking and confectionary industries due to their physicochemical properties. Jackman (1988) studied the functional properties of whey and potato protein preparations and found that the functional properties of potato proteins can be enhanced by blending them with whey proteins. He suggested that studies of the effects of differentiated protein structures on their functional properties can be useful in determining the nature of protein-protein interactions, likely due to blending of protein whey with proteins present in potato or other vegetables.

In general, potato protein preparations obtained through thermal coagulation exhibit a high content of total protein (>80%), low ash content (1.5-3.0%), light colour, hardly

any potato flavour and aroma, low (<50%) solubility and also water and oil absorption, especially when the conditions of thermal coagulation of the juice were at low pH (Knoor *et al.* 1977; Knoor 1980a, 1980b, 1982). Although potato proteins soluble in water and exhibiting emulsifying properties can be obtained by coagulation at room temperature, the resultant product is dark in colour and tastes unpleasant, its ash content is high and its digestibility is reduced (Knoor 1978; Knoor 1980a; Wojnowska *et al.* 1981). The results of studies reported by several authors (Kapoor *et al.* 1975; Ralet and Gueguen 2000; van Koningsveld *et al.* 2001) show that it is possible to obtain potato proteins light in colour and hardly reminding of potato flavour and aroma, exhibiting desired functional properties, but their recovery is too costly, since it requires separation of glycoalkaloids and phenolic compounds and also removal or inactivation of antinutrients, such as protease inhibitors, or separation of protein fractions by chromatography techniques. One of the most efficient methods used for reducing the content of cumbersome substances in food is coagulation at elevated temperatures. However, too high temperature can affect the structure of proteins and change their conformation, solubility, digestibility and functional properties (Zayas 1997; Milewski 2001; Sikorski 2001).

POSSIBLE APPLICATIONS

Protein preparations have been used in the food industry (e.g. meat processing) for many years, for economical reasons and also in order to change the functional properties and the nutritional value of food products. Recently, a product 'Satise' has been marketed on the Canadian market as a high-calorie diet supplementation, containing an inhibitor of proteolytic proteins, which is thought to increase the effects of cholecystokinin (CKK), a hormone, which increases the feeling of satiety (fullness) (World News 2005). Another, interesting potato preparation is Solanic, developed by the Dutch company Avebe in 2007 (Anonymous 2007). A director of Avebe subsidiary Solanic claimed the preparation has a vegetable protein with similar functionality to animal-based products and can be a good alternative in foaming, emulsifying or even gelling.

The effects of protein preparations on the quality of food products vary, depending on the origin of protein, its denaturation degree (native protein, partially or completely denaturated), the content of non-protein compounds, e.g. fats, carbohydrates and minerals, and also type of product (**Table 6**). The supplementation with native protein (isolates, concentrates) has a greater impact, also negative, on bread volume, expansion index or on the texture of extruded products and other functional properties of food than non-denaturated protein supplements (Zayas 1997; Lusas and Rooney 2001). On the other hand, the effects of protein supplements containing denaturated protein on the qualitative parameters of e.g. extruded products are lesser and they are primarily dependent on the activity of the water present in the preparation, solubility, protein denaturation degree and origin (from plants or animals). The effects of potato protein preparations (cooked potato and concentrates of thermally coagulated protein) added to bread are relatively well known (Knoor 1977, 1979). Addition of a protein preparation to bread affects both its physical changes and its nutritional value. According to Knorr (1977), 30% addition of a potato protein concentrate increased the nutritional value of bread (PER increased from 0.51 to 0.95). Pęksa (2006) and Pęksa *et al.* (2007) observed positive effects of a preparation containing coagulated potato protein on the properties of fried potato products (3^{rd} generation snacks), especially their texture.

Potato protein preparations can also be added to extruded snack products. Extrusion is a technology that has become quite common and its popularity is steadily increasing in food processing, since it enables the use of components, difficult to use in traditional recipes, e.g. fats, fiber and proteins (Schuler 1986; Hsieh *et al.* 1989; Lue *et al.* 1991; Guy 1992; Croghan 1998; Virtucio 1999; Mendonça *et al.* 2000; Lusas and Rooney 2001; Pęksa 2001; Kita *et al.* 2002; Pęksa *et al.* 2004, 2007). However, the use of proteins in extruded products is restricted by qualitative and quantitative factors. For example, addition of a protein preparation exhibiting high water absorption requires adequately increased amounts of water, which, depending on the type of product and extrusion may result in significant limitations in protein supplementation.

Some authors studied the influence of chemical, enzymatic or physical modifications of plant proteins, like succinylation, acylation, phosphorylation or hydrolysis on functional properties, mainly from legumes (El-Adawy 2000; Kowalczyk and Baraniak 2005), soy (Chan and Ma 1999) or rapeseed (Krause 2002). Their methods of protein modifications improved the emulsification and foaming properties (succinylation) or water solubility (acylation) of preparations. Good anti-oxidative ability of preparations of hydrolyzed plant proteins after their earlier acetylation was claimed by Kowalczyk and Baraniak (2005).

There is a shortage of knowledge about potato protein modifications. However, according to Kamnerdpetch *et al.* (2007) the hydrolysis of potato pulp by the combination of endoprotease and exopeptidase let to an increase in the amino acid concentration, especially aromatic amino acids,

Table 6 The effects of protein preparations addition on food quality.

Protein preparation	Food quality	References
Protein product recovered from potato starch waste effluents by heat coagulation	Protein enrichment of bread, bread quality	Knoor 1977, 1979
Defatted soy flour, beef protein	Physical and sensory properties of extruded snacks	Park *et al.* 1993
Protein products and preparations	The quality of extruded cereal snacks	Obuchowski and Michniewicz 1993
Proteins of different origin and form	Functional and nutritive quality of different food products	Giese 1994
Milk and legume or corn protein products	Physical properties of cereal extruded snacks	Fornal and Majewska 1995; Szpendowski *et al.* 1996
Proteins of different origin and form	Functional properties of different food products	Zayas 1997
Whey proteins	Functional properties of different food products	Leman 1999
Corn proteins	Creation of the physical features of extruded snacks	Batterman-Azcona *et al.* 1999
Different protein preparations	Creation of food structure as an effect of interaction between proteins and saccharides, fat, water or other proteins	Angeles *et al.* 2001
Protein preparations of different origin, denaturation degree, the presence of non-protein compounds	Improvement the quality of extruded snacks	Huber 2001; Lusas and Rooney 2001
The origin of protein preparation, denaturation degree	Improvement food nutritional quality	Sikorski 2001
Milk proteins	Improvement the nutrient-density of snack products	Onwulata *et al.* 2001
Potato protein preparation	The consistence of mashed potato	Pęksa *et al.* 2002
Soy protein products	The quality of fried wheat-corn snacks	Senthil *et al.* 2002
Spent hen meat	Physical properties of cereal snacks	Lee *et al.* 2003

and can be used to improve the quality of potato protein. Possible modification of potato protein could be an alternative way for enlarging its applications. Potato protein can also be modified for improvement through traditional plant breeding or genetic engineering. Much of the focus on potato breeding and development in the past has focused on increasing yield and developing pest and disease resistance (Lister and Munro 2000; Rockhold *et al.* 2001).

For improved protein the tetraploid hybrids of Andigena and the diploid hybrids *Phureja-Tuberosum* parents in selection program with Tuberosum were used (Snyder and Desborough 1978; Desborough 1985). These selections had a wide range of protein content (maximum from 8 to 9%) and were used to study the relationship of albumin, globulin, prolamine and glutelin fractions to total protein. A positive correlation was found between the quantity of either albumin or globulin and total protein within a clone. This indicated that selection for higher tuber protein did not preferentially elevate either soluble fractions, although their quantities increased. It was also stated that although these hybrids had high nutritional quality protein, they lacked the yield potential when compared to commercial cultivars.

Developing high quality plant proteins by genetic engineering presents greater opportunities. Potatoes are relatively easy to transformation using *Agrobacterium tumefaciens*, and plantlets are readily regenerated and clonally propagated. Studies were carried out to select clones of potatoes that had up to three times the free methionine content of the control (Lister and Munro 2000; Pribylova *et al.* 2006).

In recent years the use of plants as bioreactors has become an attractive method for the production of polypeptides for pharmaceutical or technical purposes (Goddijn and Pen 1995; Herbers and Sonnewald 1999, Zimnoch-Guzowska *et al.* 2004; Pribylova *et al.* 2006). Transgenic potato plants were used to express an edible proinsulin or insulin and developed in an attempt to protect against cholera (Arakawa *et al*. 1998), synthesizing pharmaceutical polypeptides, such as human albumin, epidermal growth factor or calcitonin (Salmanian *et al*. 1996; Ofoghi *et al.* 1999), production an edible vaccine protecting against enterotoxigenic *E. coli* (causing diarrhoea), other antigens such the capsid protein of Norwalk virus (protection against gastroenteritis) (Mason *et al.* 1996).

The results of the studies directed on the effects of molecular properties of proteins, environmental and technological factors effecting functional properties of potato protein preparations, especially those connected with their solubility and hydrophobicity, can be useful in anticipating the functional properties of protein preparations and better understanding of their role and efficiency when used as food components and supplements. The studies carried out so far have been exclusively empirical. Further studies, aimed at elaboration of standard methods for the production of potato protein preparations and the effects of potato protein supplementation on functional properties of food products are required.

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