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Effect of Fortification with Different Starches on Starch Digestibility, Textural and Ultrastructural Characteristics of Sweet Potato Spaghetti

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Abstract

The effect of fortification with various sources of starch such as banana, lentil, black gram and sweet potato in reducing the *in vitro* starch digestibility and glycaemic index of sweet potato spaghetti was investigated at Central Tuber Crops Research Institute, Thiruvananthapuram, India. Swelling index and cooking loss were more for the starch-fortified spaghetti than the control spaghetti. Among the starches, highest cooking loss was obtained for 10% lentil starch fortified sample. Crude protein content was higher for black gram and sweet potato starch fortified spaghetti. *In vitro* starch digestibility increased very slowly from 20-120 min, for the fortified samples compared to the unfortified controls. Accordingly, the rapidly digestible starch (RDS) was less and resistant starch (RS) was more for the starch-fortified samples. The estimated glycaemic index (EGI) was low for the spaghetti fortified with banana, lentil and sweet potato starches at 5 and 10% levels, indicating that these could be considered as low glycaemic foods. Firmness of cooked spaghetti was maximum for black gram starch fortification, while toughness was the maximum for lentil starch based cooked samples. Ultrastructural studies showed starch gelatinization and leaching with diffused granular shape for most spaghetti samples. Whey protein concentrate promoted starch-protein network formation leading to slow starch digestibility.

Key words: Sweet potato, sphagetti, ultrastructure, starch digestibility

Introduction

Traditional pasta, with its origin in Italy is made from durum wheat semolina and has gained worldwide popularity as an easy-to-cook food (Feillet and Dexter, 1996; Malcolmson et al., 1993). With the increasing health consciousness of consumers, pasta has also undergone drastic transformations in its composition, incorporating various health contributing additives. Pasta is generally reported as a low glycaemic food, resulting primarily from the starch-protein network formation during the extrusion process (Björck et al., 2000; Fardet et al., 1998). The low glycaemic response of pasta imparts a therapeutic value to it and it finds use in the treatment of obesity and Type 2 diabetes mellitus (Giese, 1992). Several studies have been made to increase the nutritive and functional value of pasta through fortification with proteins, dietary fibres, resistant starches, legume flours, banana flour etc. (Tudoricã et al., 2002; Brennan et al., 2004; Sadehi and Bhagya, 2008; Petitot et al., 2010; Goñi and Valentin-Gamazo, 2003).

Pasta or spaghetti has been made from non-wheat ingredients or their blends with wheat which gives various functional attributes to the product (Mastromatteo et al., 2012; Gallegos-Infante et al., 2010; Padalino et al., 2011). Sweet potato has been recognized as a low glycaemic food with a glycaemic index (GI) < 55, which makes it an ideal food for diabetic people. The possibility of using sweet potato, a low glycaemic food, for making pasta or spaghetti was explored by various workers (Collado and Corke, 1996; Linmroongreungrat and

Huang, 2007; Jyothi et al., 2011; 2012). Sweet potato starch noodles have been commercially produced in countries like China and Japan and the improvement in quality through fortification with other starches/flours has also been reported (Chen, 2003; Lee et al., 2005; Tan et al., 2006; Thao and Noomhorn, 2011). High protein or dietary fiber enriched pasta was reported from sweet potato (Jyothi et al., 2011; 2012). Fortification of pasta/spaghetti with resistant starch sources has been reported to reduce its starch digestibility and decrease the postprandial glucose and insulin responses (Sajilatha et al., 2006; Gelencsér et al., 2008). Glycaemic index of pasta, spaghetti/noodles etc. has been reduced by fortifying the mixes with ingredients rich in resistant starch (RS) content. Unripe banana flour is reported to contain 47-57% RS (Faisant et al., 1995) and has been used in the preparation of starch noodles (Villalobos et al., 2008). There are a number of reports on the effect of legume flours in reducing the glycaemic response of foods (Goñi and Valentin-Gamazo, 2003; Gallegos-Infante et al., 2010). The present investigation focuses on the nutritional, physico-mechanical and ultrastructural characteristics of sweet potato spaghetti fortified with RS rich sources like banana starch and starches from black gram, lentils and sweet potato.

Materials and Methods

Raw materials

Pale cream fleshed, white skinned sweet potato variety, Sree Arun grown at the Research Farm, Central Tuber Crops Research Institute (CTCRI), Thiruvananthapuram, India, was used for the study. Roots harvested at 105 days after planting were cleaned free of dirt, peeled and sliced to round discs of 0.5 mm thickness. The pieces were soaked in 1.0% acetic acid (1:5w/v) for 1h to eliminate the browning problem. The soaked pieces were washed in fresh water and dried in sunlight for 36 h. Dry chips were powdered in a hammer mill and sieved (pore size: 355 µm) to obtain fine flour.

Other raw materials used for the study included black gram (*Vigna mungo*), red lentil (*Lens culinaris*) and banana (nendran variety) (*Musa paradisiaca*) starches. Refined wheat flour (hereinafter called 'maida') was purchased from the local market. Whey protein concentrate (WPC) with a crude protein and fat content of 70% and 4.32% respectively was purchased from M/s Maahaan proteins Ltd. Uttar Pradesh, India.

Preparation of starch

Unripe banana (nendran variety), purchased from the local market, was peeled and the round slices (*Ca*. thickness 0.5mm) were soaked in 0.125% potassium metabisulphite (1:5 w/v) for 1 h to prevent the discolouration of starch. The chips were drained and ground to a fine paste in a kitchen blender, with adequate quantity of water. The slurry was then filtered through the starch sieve (pore size 75µm). The starch slurry was allowed to settle at room temperature (30 ± 1°C) for 18-24 h and the settled starch cake was dried in the sunlight for 36 h and ground to a fine powder.

Legumes, purchased from the local market, were soaked overnight in water and after draining the water, the soaked grams were separately blended to a fine paste in a kitchen blender (1:5 w/v). In the case of black gram, 0.1 M ammonia (NH_4OH) was used for the first extraction to avoid the interference of mucilage in the release of starch. The slurries were squeezed through a muslin cloth and the residues were reground to facilitate the complete release of starch. The combined slurries were allowed to settle for 18-24 h at room temperature (30 ± 1°C); after which the starch cakes were dried in the sun light for 36 h, powdered and stored in air tight containers till use.

Sweet potato starch was extracted from the peeled tuber slices soaked in 0.25% potassium metabisulphite, by grinding in a blender with adequate quantity of water. The starch slurry was filtered through fine mesh sieve and the starch cake collected after 24 h settling was dried, powdered and stored for use.

Spaghetti formulations

Control spaghetti formulations contained 85% maida, 10% WPC and 5% refined sun flower oil (C1) and 72% sweet potato flour, 13% maida, 10% WPC and 5% oil (C2). Various starches were added at three levels viz., 5%, 10% and 15%, out of which 2% was gelatinized with water by the double plate method by keeping the slurry in a boiling water bath and adding back to the respective mixes. Treatment details are given in Table 1.

Preparation of spaghetti

The various ingredients were mixed with the requisite quantity of water to achieve proper hydration, so that

Table 1. Percentage incorporation of various ingredients in starch-fortified sweet potato spaghetti

Treatments	Ingredients (%)					
	Sweet potato flour (SPF)	Whey protein concentrate (WPC)	Starch*	Gelatinized starch**	Oil	Maida
1	67	10	3	2	5	13
2	62	10	8	2	5	13
3	57	10	13	2	5	13

* From the respective sources such as banana, black gram, lentil and sweet potato;** the respective starches were gelatinized and added back to the mix

the extruded spaghetti had a smooth outer finish, with no checking. The mix was then put to the mixing chamber of the Pasta making machine (Model P3; M/s La Monferrina, Italy). Spaghetti was extruded at room temperature using the die having thin round holes of diameter 0.1 mm. The extruded spaghetti was then spread on a tray for one hour at room temperature, after which the samples were dried in an oven at 50°C for 18 h to reduce the moisture content to < 12%.

Cooking procedure

Spaghetti samples were uniformly dried to a constant weight at 105°C for 2 h. Fifty grams of dry spaghetti was added to 500 ml water containing 1.0 g sodium chloride. Optimum cooking time for each sample was determined using the Approved Method 66-50 (AACC, 2000) and corresponded to the disappearance of the white central part of the spaghetti. Samples were then drained and the water was collected to a previously weighed dish. Cooked samples were surface dried using a thin muslin cloth and then weighed to assess the swelling index (SI). The SI was determined by the method of Mestres et al. (1988) as (weight of cooked spaghetti-weight of dry spaghetti)/weight of dry spaghetti. The cooking loss (%) was determined by drying the drained water from cooked spaghetti at 105° C and expressing the weight of dry residue as percentage of the original spaghetti sample (Debbous and Doctkott, 1996).

Nutritional profile

Nutritional parameters like starch, total sugars, crude protein and fat in the cooked spaghetti were determined as per the procedures reported earlier (Jyothi et al., 2012). Starch and total sugars were determined by the method of Moorthy and Padmaja (2002), while crude protein was quantified by Kjeldahl method (AOAC, 1995). Fat content was determined by the solvent extraction method of Folch et al. (1957).

Starch digestibility characteristics and glycaemic index

In vitro starch digestibility of starch fortified sweet potato spaghetti was determined by the procedure modified from the original methods of Englyst et al. (1996), McCleary and Monaghan (2002) and Kim et al. (2008). Spaghetti samples were cooked as described earlier and the cooked samples were surface dried on Whatman No.1 filter paper. Cooked spaghetti (5.0 g) was cut into small pieces of *Ca.* 1.0 mm length, mixed with HCl-KCl buffer (pH 1.5; 10 ml) and kept in a water bath (SW21; M/s Julabo Industries) at 37°C for 10 min. Pepsin (EC 3.4.23.1; M/s SIGMA, USA) was added to initiate proteolysis (0.4 ml per sample from an enzyme solution containing 1.0 g pepsin/10ml HCl- KCl buffer). Samples were incubated at 37°C for one hour, after which 40 ml sodium phosphate buffer (0.02M; pH 6.9 containing 0.12 M sodium chloride) was added. One tablet of Panzynorm-N (manufactured by M/s German Remedies India Ltd., Mumbai, India) containing 10,000 units of lipase, 9000 units of amylase and 500 units of protease was dissolved in 5.0 ml sodium phosphate buffer (0.1M; pH 8.0) and one milliliter each was added to the samples and incubation continued for 120 min. Enzyme and substrate blanks were maintained for each sample. Sample aliquots (1.0 ml) were drawn from the assay system after every 20 min interval up to 120 min, added to 3.0 ml sodium acetate buffer (0.2M; pH 4.8) and incubated at 60°C for further 10 min with 0.25 ml dextrozyme GA (M/s Novo Industries, Denmark). Glucose released in each system was quantified by the Glucose oxidase (EC 1.1.3.4) - PAP method (M/S Beacon Diagnostics Pvt. Ltd., Gujarat, India). Glucose released at each time from 20 to 120 min was expressed on 100 g starch basis for each spaghetti to nullify the difference in starch content between the formulations.

Starch fractions such as rapidly digested starch (RDS), slowly digested starch (SDS) and resistant starch (RS) were computed from the data on the *in vitro* kinetics of starch hydrolysis in the spaghetti as given below:

RDS = Glucose released at 20 min x 0.9/100 g starch in spaghetti

SDS = (Glucose released at 120 min x 0.9 per 100 g starch) – RDS

RS = Total starch in spaghetti (g/100 g cooked spaghetti on dry weight basis) – (RDS + SDS)

The hydrolysis index (HI) was calculated as:

HI = Total glucose released from 100 g cooked sample (on dry weight basis) at 120 min x 100

Total glucose released from 100 g white bread at 120 min (on dry weight basis)

Estimated glycaemic index (EGI) was computed using the formula of Goñi et al. (1997).

EGI = 39.71 + 0.549 x HI

Texture profile analysis

Textural properties of the dry as well as cooked spaghetti (six replicates) were measured using a Food Texture Analyser TAHDi (M/s Stable Microsystems, UK). Shear test/cutting test was performed using HDP/BSK Blade set with knife and the experimental conditions were: Method: Measure force in compression; Mode: Return to start; Pre-test speed: 2mm/s; Test speed: 2mm/s; Post test speed: 2mm/s; Distance: 10mm; Trigger force: 5.0 g. From the force-distance/time curve, the peak force is taken as the firmness (hardness) and the area under the curve is taken as the toughness.

Ultrastructural studies

Immediately after cooking, the samples were surface dried by blotting the adherent water on a filter paper (Whatman No. 1) and were transversely cut using a razor blade. The sample was mounted onto brass stubs using double-sided carbon conductive adhesive tape. Gold coating (10-15 mm thick) was then applied using JEOL JFC 1600 magnotron sputtering unit with 10 mA current for 80 seconds. The coated samples were examined at 10kV and 1Pa vacuum using a JEOL JSM6390 LV scanning electron microscope (Oxford, UK).

Statistical analysis

The data reported are the mean (± standard deviation) of triplicate analysis. Data were analyzed using the statistical package SAS 9.3 to perform ANOVA (SAS, 2010). The treatments were considered statistically significant at 5% level ($P \leq 0.05$). The mean comparisons were made by the Duncan's Multiple Range Test (DMRT).

Results and Discussion

The increasing awareness about the health contributing bioactives in sweet potato roots coupled with its low glycaemic nature has enhanced the food value of the crop, especially in countries where it is largely cultivated. An attempt was made to develop sweet potato spaghetti with various resistant starch sources and study its nutritional, starch digestibility and ultrastructural characteristics.

Cooking characteristics

The cooking characteristics of the starch-fortified sweet potato spaghetti indicated that the swelling index increased in the fortified group (Table 2). Level of starch fortification had a significant effect in the case of banana starch with high SI in 10% and 20% starch-fortified spaghetti. However, a reverse pattern was observed in the case of black gram and sweet potato starches, indicating that water absorption was not proportionate with the level of incorporation. Control spaghetti (C2) having 72% SPF and 13% maida had higher SI (1.49) than the maida-based spaghetti (C1;1.18), which was due to the high water absorption capacity of sweet potato flour. Sweet potato and black gram starches at 5% fortification enhanced the SI, while this type of enhancement was observed in the case of banana and lentil starches only at 15% incorporation. Working with various legume flours and their protein concentrates, Bahnassey and Khan (1986) reported that the type of legumes significantly influenced the cooked weight of spaghetti. Sweet potato pasta containing 75% sweet potato flour was found to require a high hydration level of 50% for proper hydration and had a SI of 1.43 (Jyothi et al., 2011). Cooking loss was increased significantly in the sweet potato spaghetti, compared to C1 (Table 2). Among the various starch-fortified spaghetti, least

Table 2. Cooking characteristics of starch-fortified sweet potato spaghetti

Treatments*	Swelling index	Cooking loss(%)
C1	1.18 ± 0.09^{h}	4.37 ± 0.33^{h}
C2	1.49 ± 0.09^{fg}	12.35 ± 0.29^{efg}
BS1	1.35 ± 0.02^{g}	11.24 ± 0.18^{g}
BS2	1.64 ± 0.04^{ef}	12.94 ± 0.88^{def}
BS3	2.29 ± 0.15^{ab}	13.60 ± 0.47^{cde}
LS1	1.90 ± 0.04^{cd}	14.81 ± 0.88^{bc}
LS2	1.90 ± 0.09^{cd}	16.98 ± 1.53^{a}
LS3	2.18 ± 0.08^{b}	14.88 ± 0.85^{bc}
BGS1	2.42 ± 0.24^{a}	15.20 ± 0.88^{b}
BGS2	1.80 ± 0.06^{de}	14.34 ± 0.44^{bcd}
BGS3	1.99 ± 0.08^{c}	13.60 ± 1.30^{cde}
SPS1	2.18 ± 0.03^{b}	15.38 ± 0.57^{b}
SPS2	1.96 ± 0.04^{cd}	11.86 ± 0.55^{f}
SPS3	1.82 ± 0.03^{cd}	11.32 ± 1.09^{g}

* C1: 85% maida, 10% WPC and 5% refined sun flower oil; C2: 72% sweet potato flour, 13% maida, 10% WPC and 5% oil; BS1: 5% banana starch; BS2: 10% banana starch; BS3: 15% banana starch; LS1: 5% lentil starch, LS2: 10% lentil starch; LS3: 15% lentil starch; BGS1: 5% black gram starch; BGS2: 10% black gram starch; BGS3: 15% black gram starch; SPS1: 5% sweet potato starch; SPS2: 10% sweet potato starch; SPS3: 15% sweet potato starch

Mean (± SD) of triplicate analysis; values followed by different superscripts in each column are significantly different

cooking loss (%) was observed for 10% and 15% SPS and 10% BS-fortified samples. Increasing the percentage incorporation of starch decreased the cooking loss for black gram and sweet potato starch-fortified spaghetti, while highest cooking loss of 16.98% was obtained for 10% lentil starch-fortified spaghetti. Approximately 8-10% cooking loss was reported in chick pea flour fortified spaghetti, compared to 7.53% in 100% wheat flour spaghetti (Abou Arab et al., 2010), while 9.86% cooking loss was reported in 10% WPC- fortified maida spaghetti (Baskaran et al., 2011). Decrease in cooking loss by higher levels of SPS and BGS indicated that these starches formed a firmer network during pasta making and cooking than other starches.

Nutritional profile

Cooked pasta samples were analysed for its nutritional quality and the various parameters are shown in Table 3. In the control spaghetti, 85% was made up of either maida alone (C1) or sweet potato-maida blend (C2) and hence the contents of starch and protein were almost similar, with slightly higher values for total sugars and fat. However, in the case of all the treatments enriched with various types of starches, there was obviously higher starch content, although the final starch content depended on the extent of leaching from cooked samples. This was particularly evident from the difference in starch content among the samples. Higher starch content was observed in the samples fortified with 10% starch in all cases, except in the case of banana starch, where 15% starch fortification resulted in higher starch content. Banana starch is reported to have high structural stability resulting from the high amylose content (*Ca.* 30%) and degree of crystallinity of amylopectin (Gallant et al., 1997; Blazek and Copeland, 2008). When compared to the control spaghetti samples, starch-fortified spaghetti had higher sugar content for most samples. Starches were fortified at the expense of sweet potato flour and hence lower sugar values are expected for the fortified spaghetti. Increase in sugar content observed in the cooked spaghetti indicated that there is partial conversion of starch to sugar/lower molecular weight dextrins with exposed reducing groups during cooking. Residual β amylase in sweet potato flour may be preferentially acting on the unbound starches in the fortified samples.

Black gram and sweet potato starch fortified spaghetti samples had higher crude protein content than others. Many starches especially those isolated from legumes have bound proteins and this might have led to the high protein content in the starch fortified spaghetti. However, Thao and Noomhorn (2011) reported that starches from four sweet potato varieties contained 0.15 to 0.23% protein as compared to 0.16% in mung bean starch. On the contrary, Goñi and Valentin-Gamazo (2003) reported very high protein content in wheat spaghetti (16.2%) and wheat-chick pea flour spaghetti (17.0%). We had earlier reported crude protein contents of 5.14% in sweet potato pasta containing 70% sweet potato and 27% refined wheat flour and 9.41% in pasta fortified with 10% whey protein concentrate (WPC) (Jyothi et al., 2011). All the formulations in the present study also contained 10% WPC and hence a substantial quantity of protein might have been contributed by WPC. The WPC sample (Procon 3700) used in this study had a crude protein content of 70%, as reported by the manufactureres. Ovando-Martinez et al. (2009) reported that spaghetti fortified with banana flour (30%) had a

Table 3. Nutritional characteristics of starch-fortified sweet potato spaghetti (on dry weight basis)

Treatments*	Crude protein** (%)	Total starch (%)	Total sugars (%)	Fat content (%)
C1	9.63	68.49 ± 0.34[i]	4.02 ± 0.01[j]	4.13 ± 0.16[d]
C2	9.92	69.70 ± 0.32[h]	4.70 ± 0.02[h]	5.02 ± 0.08[a]
BS1	10.79	72.30 ± 0.32[g]	4.99 ± 0.01[g]	3.98 ± 0.15[de]
BS2	8.75	76.33 ± 0.34[d]	6.35 ± 0.19[b]	4.78 ± 0.03[b]
BS3	9.92	81.30 ± 0.19[a]	5.35 ± 0.01[e]	4.55 ± 0.05[c]
LS1	9.05	75.36 ± 0.19[e]	3.82 ± 0.02[k]	5.05 ± 0.13[a]
LS2	11.38	77.37 ± 0.18[c]	5.19 ± 0.02[f]	4.65 ± 0.09[bc]
LS3	10.21	72.22 ± 0.17[g]	5.95 ± 0.04[d]	3.88 ± 0.08[e]
BGS1	11.96	75.25 ± 0.33[e]	4.31 ± 0.01[i]	4.98 ± 0.10[a]
BGS2	12.25	78.26 ± 0.02[b]	6.16 ± 0.04[c]	4.63 ± 0.08[bc]
BGS3	11.96	72.22 ± 0.48[g]	6.94 ± 0.05[a]	4.70 ± 0.05[bc]
SPS1	12.26	72.19 ± 0.32[g]	5.18 ± 0.01[f]	3.87 ± 0.08[e]
SPS2	11.08	75.40 ± 0.34[e]	6.93 ± 0.01[a]	4.68 ± 0.03[bc]
SPS3	11.08	73.14 ± 0.19[f]	5.98 ± 0.02[d]	5.07 ± 0.08[a]

* C1: 85% maida, 10% WPC and 5% refined sun flower oil; C2: 72% sweet potato flour, 13% maida, 10% WPC and 5% oil; BS1: 5% banana starch; BS2: 10% banana starch; BS3: 15% banana starch; LS1: 5% lentil starch, LS2: 10% lentil starch; LS3: 15% lentil starch; BGS1: 5% black gram starch; BGS2: 10% black gram starch; BGS3: 15% black gram starch; SPS1: 5% sweet potato starch; SPS2: 10% sweet potato starch; SPS3: 15% sweet potato starch. ** Duplicate analysis; others are Mean (± SD) of triplicate analysis; values followed by different superscripts in each column are significantly different

crude protein content of 9.35%, while Gallegos-Infante et al. (2010) obtained a protein content of 16.68% in spaghetti fortified with common bean (*Phaseolus vulgaris)* flour. Purified banana starch was used in our study and hence the increase in protein was not highly significant, as in the case of legume or banana flour, except for black gram starch fortified spaghetti (Table 3).

Fat content was lower in the spaghetti formulations containing 5% banana and sweet potato starches (Table 3). Nevertheless, when starch incorporation was increased to 10 and 15%, the fat content also increased for these combinations, while for the black gram and lentil starch based spaghetti, decrease in fat was observed with higher level of starch fortification. This indicated that the bound lipids in the various starches are not uniform and they might contribute to such differences. It is also possible that there is a preferential loss of fat from the lentil starch-fortified spaghetti, on cooking. Kim et al. (1996) reported that proteins and lipids played a crucial role in minimizing cooking loss in starch noodles, through the formation of amylose complexes. In our study also, highest cooking loss was observed for lentil (15%) starch-fortified sweet potato spaghetti (Table 2).

Sugar (reducing groups) content was higher in spaghetti fortified with higher levels of starches, than the controls (C1 and C2). Since starch fortification was at the expense of sweet potato flour, the increase in starch indicated a probable exposure of reducing group of the amylose during the cooking process, which makes it partially soluble.

In vitro starch digestibility and starch fractions

Starch digestibility pattern was studied using cooked samples of starch-fortified sweet potato spaghetti. It was found that as compared to the maida-based control spaghetti (C1), digestion proceeded very slowly for the various starch-fortified samples (Table 4). When 76 and 82 g glucose were released respectively from 100 g starch in C1 and C2 spaghetti, the glucose release was only 67-72% for the starch-fortified spaghetti (Table 4). Among the four types of starches used, maximum amount of glucose was released from black gram starch-fortified spaghetti.

Quantification of starch fractions showed that the rapidly digested starch (RDS) was maximum for the control spaghetti (Table 5). Sweet potato starch (10%) and

Table 4. Time course release of glucose from starch-fortified sweet potato spaghetti (expressed as g glucose 100 g^{-1} starch in cooked spaghetti on dry basis)

Treatments*	Time (min.)					
	20	40	60	80	100	120
C1	65.81^{a}	68.25^{a}	73.50^{a}	76.14^{a}	77.64^{a}	82.23^{a}
C2	61.90^{b}	66.47^{b}	67.64^{b}	69.45^{b}	73.93^{b}	76.77^{b}
BS1	56.47^{d}	57.88^{d}	59.24^{e}	60.90^{e}	63.49^{e}	67.48^{d}
BS2	54.16^{e}	55.38^{ef}	58.69^{e}	60.11^{ef}	62.23^{ef}	64.59^{ef}
BS3	49.28^{g}	52.10^{h}	55.01^{f}	57.54^{hi}	60.62^{f}	62.86^{fg}
LS1	50.27^{fg}	52.48^{gh}	56.00^{f}	59.10^{fg}	61.62^{ef}	65.08^{e}
LS2	50.10^{fg}	53.91^{fg}	55.22^{f}	58.57^{gh}	61.98^{ef}	64.38^{ef}
LS3	57.48^{cd}	60.90^{c}	64.60^{cd}	68.22^{bc}	70.49^{c}	72.02^{c}
BGS1	51.19^{f}	56.41^{de}	59.21^{e}	62.59^{d}	65.25^{c}	68.63^{d}
BGS2	53.42^{e}	56.70^{de}	58.67^{e}	60.13^{ef}	62.15^{ef}	65.30^{e}
BGS3	58.12^{c}	62.04^{c}	65.31^{c}	67.43^{c}	69.66^{c}	71.31^{c}
SPS1	50.89^{f}	53.61^{gh}	55.29^{f}	57.40^{hi}	60.42^{fg}	61.78^{g}
SPS2	45.41^{h}	48.29^{i}	51.75^{g}	56.08^{i}	58.74^{g}	61.17^{g}
SPS3	51.36^{f}	56.93^{de}	63.17^{d}	67.05^{c}	68.80^{c}	70.96^{c}

* C1: 85% maida, 10% WPC and 5% refined sun flower oil; C2: 72% sweet potato flour, 13% maida, 10% WPC and 5% oil; BS1: 5% banana starch; BS2: 10% banana starch; BS3: 15% banana starch; LS1: 5% lentil starch, LS2: 10% lentil starch; LS3: 15% lentil starch; BGS1: 5% black gram starch; BGS2: 10% black gram starch; BGS3: 15% black gram starch; SPS1: 5% sweet potato starch; SPS2: 10% sweet potato starch; SPS3: 15% sweet potato starch. Mean of triplicate analysis; values followed by different superscripts in each column are significantly different

banana starch (15%) fortification gave spaghetti with the least RDS content. Slowly digested starch (SDS) was the lowest for banana starch (15-10%) and SPS (5%) fortified spaghetti. Resistant starch (RS) content which represented the undigestible fraction of starch in the spaghetti, was the lowest in the control samples, indicating that these were the most digestible. Highest RS retention was observed in SPS-fortified spaghetti (36-45%). Goñi and Valentin-Gamazo (2003) reported significantly lower starch digestibility in boiled wheat spaghetti and wheat-chick pea spaghetti (75:25), which also retained higher levels of indigestible starch. Pasta or spaghetti has been widely recognized as a low glycaemic food and fortification with non-traditional ingredients to further reduce its starch digestibility has been attempted by several workers (Gelencsér et al., 2008; Petitot et al., 2010; Tudoricã et al., 2002). Sweet potato pasta with low *in vitro* starch digestibility was made with different protein sources like whey protein concentrate, defatted soy flour and fish powder, which also had RS content of 9.7 to 17% (Jyothi et al., 2011). The product developed in this study had much higher RS content. Protein-starch interactions in spaghetti are reported to affect the amylolysis of starch by restricting the entry of α-amylase into the network structure during cooking (Petitot et al., 2010). Although the level of WPC was uniform (10%) in the present study, the variations in the RS retention indicated that there could be firmer network formation between the pure starch sources and WPC in the fortified spaghetti than the starch occurring in the flour (C1 and C2) and WPC. Kim et al. (2008) also reported that increased accessibility to starch could occur in case of loose starch-protein network. Vatanasuchart et al. (2012) observed that there was a significant relationship between the apparent amylose in banana starch and its slow digestibility. Kaur et al. (2010) also obtained such correlation between amylose and RS content in red lentil cultivars.

Glycaemic index of the starch-fortified spaghetti was computed based on the formula of Goñi et al. (1997). It was found that all the starch-fortified sweet potato spaghetti samples had lower EGI than C1 and C2 (Table 5). Nevertheless, the decrease was not

Table 5. Quantification of starch fractions in starch-fortified sweet potato spaghetti and estimated glycaemic index (EGI)

Treatments*	Starch fractions (g 100g^{-1} starch)			EGI
	RDS	SDS	RS	
C1	59.23^{a}	14.78^{bc}	25.99^{g}	67.89^{a}
C2	55.71^{b}	13.39^{cd}	30.90^{f}	66.62^{b}
BS1	50.82^{d}	9.90^{fg}	39.27^{d}	64.27^{e}
BS2	48.75^{e}	9.39^{g}	41.87^{bc}	64.52^{e}
BS3	44.35^{g}	12.22^{de}	43.42^{ab}	65.43^{cd}
LS1	45.24^{fg}	13.32^{cd}	41.43^{c}	64.38^{e}
LS2	45.09^{fg}	12.85^{cde}	42.06^{bc}	64.79^{de}
LS3	51.73^{cd}	13.09^{cd}	35.18^{e}	65.93^{c}
BGS1	46.07^{f}	15.70^{ab}	38.23^{d}	65.79^{c}
BGS2	48.08^{e}	10.69^{efg}	41.23^{c}	65.53^{c}
BGS3	52.31^{c}	11.86^{def}	35.82^{e}	65.65^{c}
SPS1	45.80^{f}	9.80^{fg}	44.40^{a}	62.13^{g}
SPS2	40.87^{h}	14.18^{bcd}	44.95^{a}	62.90^{f}
SPS3	46.23^{f}	17.64^{a}	36.14^{e}	65.98^{bc}

*C1: 85% maida, 10% WPC and 5% refined sun flower oil; C2: 72% sweet potato flour, 13% maida, 10% WPC and 5% oil; BS1: 5% banana starch; BS2: 10% banana starch; BS3: 15% banana starch; LS1: 5% lentil starch, LS2: 10% lentil starch; LS3: 15% lentil starch; BGS1: 5% black gram starch; BGS2: 10% black gram starch; BGS3: 15% black gram starch; SPS1: 5% sweet potato starch; SPS2: 10% sweet potato starch; SPS3: 15% sweet potato starch. Mean of triplicate analysis; values followed by different superscripts in each column are significantly different

considerable, as a low GI food is reported as one having GI of < 55 (Björck et al., 2000). Goñi and Valentin-Gamazo (2003) obtained a GI of 72.8 for wheat spaghetti, while 58.9 was obtained for wheat-chick pea spaghetti. The results in the present study indicated that further modifications are required to get truly low glycaemic spaghetti from sweet potato.

Textural properties

Physico-mechanical properties like firmness and toughness were measured for the dry as well as cooked spaghetti by the instrumental method. In the dry as well as cooked forms, high firmness (N) was obtained for lentil, sweet potato and black gram-fortified spaghetti (Fig. 1a). There was a highly significant reduction in firmness in cooking, which was only 3.69 N for C1 (Fig. 1b). Toughness was the highest for BS (5%) fortified spaghetti, followed by SPS (5%) fortified sample (Fig. 1c). This had no correlation with the toughness

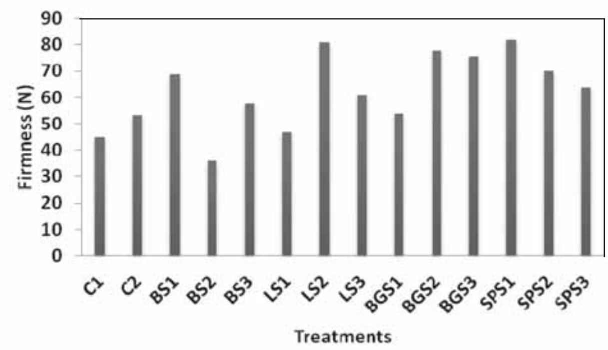

Fig.1a. Firmness of starch-fortified sweet potato spaghetti (dry samples)

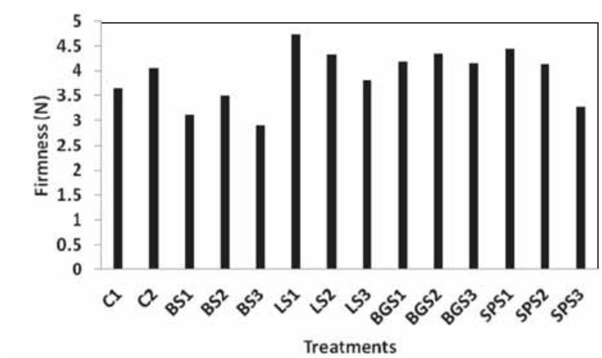

Fig.1b. Firmness of starch-fortified sweet potato spaghetti (cooked samples)

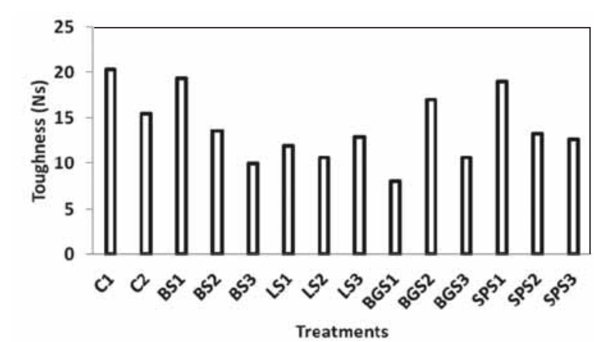

Fig.1c. Toughness of starch-fortified sweet potato spaghetti (dry samples)

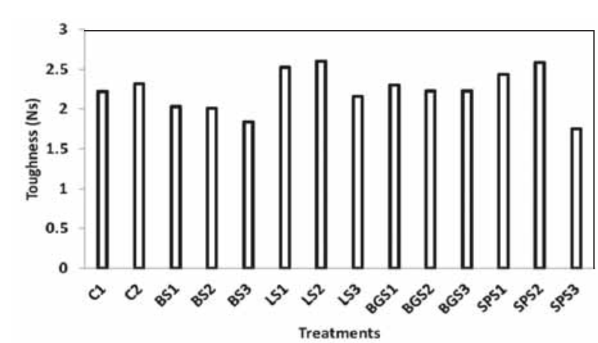

Fig.1d. Toughness of starch-fortified sweet potato spaghetti (cooked samples)

values of cooked spaghetti, where higher toughness was obtained for lentil starch and SPS (10%) fortified spaghetti (Fig. 1d). The consumer acceptance of pasta/ spaghetti is decided by its firmness, non-sticky nature and resilience.

SEM studies

The cooked spaghetti as well as the dry spaghetti samples from the control spaghetti (C1 and C2) and the spaghetti fortified with various starches was studied for their ultrastructural differences, using scanning electron microscopy (SEM) (Figs.2-6, a-d) The starch granules in the dry control spaghetti (C1) were bigger than the starch granules of sweet potato-maida control spaghetti (C2) (Fig. 2 a and c). In both cases, granules with lost shape were also visible, indicating that rupture took place during the mixing and extrusion stages itself. On cooking, the granules were swollen and diffused in the case of C1 and a closer starch-protein network was visible. However, in the case of C2, sweet potato and maida starch granules were not highly swollen as in C1 and rigid structure for a few granules were seen. There was also network formation between the starches and WPC (Fig. 2 b and d). Out of the four starches such as black gram, lentil, banana and sweet potato, banana starch fortification (5%) only resulted in dry spaghetti with the starch granules widely disperse (Fig. 3 a & 3 c). In the 10% banana fortified spaghetti, the granules were more disrupted.

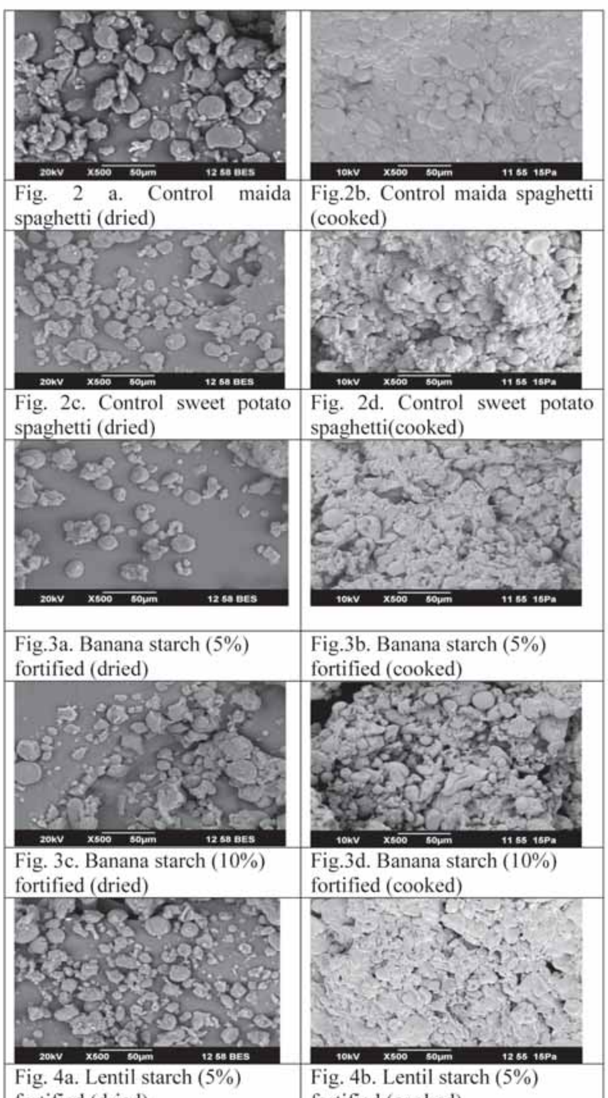

Fig. 2 a. Control maida spaghetti (dried)

Fig.2b. Control maida spaghetti (cooked)

Fig. 2c. Control sweet potato spaghetti (dried)

Fig. 2d. Control sweet potato spaghetti(cooked)

Fig.3a. Banana starch (5%) fortified (dried)

Fig.3b. Banana starch (5%) fortified (cooked)

Fig. 3c. Banana starch (10%) fortified (dried)

Fig.3d. Banana starch (10%) fortified (cooked)

Fig. 4a. Lentil starch (5%) fortified (dried)

Fig. 4b. Lentil starch (5%) fortified (cooked)

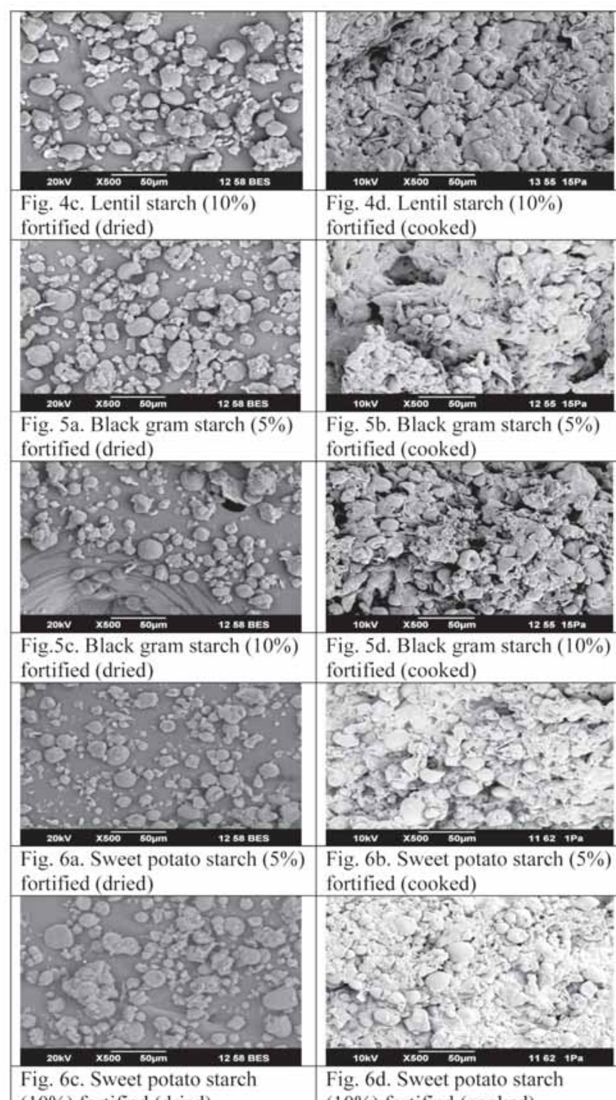

Fig. 4c. Lentil starch (10%) fortified (dried)

Fig. 4d. Lentil starch (10%) fortified (cooked)

Fig. 5a. Black gram starch (5%) fortified (dried)

Fig. 5b. Black gram starch (5%) fortified (cooked)

Fig.5c. Black gram starch (10%) fortified (dried)

Fig. 5d. Black gram starch (10%) fortified (cooked)

Fig. 6a. Sweet potato starch (5%) fortified (dried)

Fig. 6b. Sweet potato starch (5%) fortified (cooked)

Fig. 6c. Sweet potato starch (10%) fortified (dried)

Fig. 6d. Sweet potato starch (10%) fortified (cooked)

Fig. 2-6. Scanning electron micrographs (x 500) of starch-fortified sweet potato spaghetti (dry and cooked samples)

Dry spaghetti fortified with the other three starches had a large number of starch granules, of which many were having broken granular structure. Breakage occurring during the manufacturing process might have led to a disrupted ultrastructure for the starch spaghetti samples (Fig. 4 – 6 a, c). Nevertheless, on cooking, swelling of starch and leaching of amylose from granules, leading to diffused granular structure was visible. Open spaces were more seen in the case of black gram and banana (5%) fortified samples. Irrespective of the level of fortification, lentil starch-fortified spaghetti gave a highly diffused granular structure, which also led to greater cooking loss. Filamentous areas indicating starch-protein network formation were evident only at a few regions in the case of the various spaghetti samples (Fig. 4- 6 b, d). Dexter et al. (1979) reported that premixing of dough in a mixer could lead to considerable change in the structure of flours. In the present study also, we had blended the various mixes in a mixer and this might have led to disruption of granular structure in the dry spaghetti. Open areas, interconnected by fibrils of gluten protein and material leached out of swollen starch granules were reported in Japanese noodles (Dexter et al., 1979). Matsuo et al. (1978) reported a compact structure for freshly extruded wheat spaghetti, resulting from a firm starch-protein network. Various starches used in our study facilitated a firm structure for cooked spaghetti by gelatinization and mutual adhesion, as evidenced from the SEM picture. However, WPC present in the samples also promoted the formation of starch-protein network which has contributed to the slow digestibility of cooked spaghetti.

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