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Effect of Storage on *in vitro* Starch Digestibility of Functional Foods

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Authors' contributions

This work was carried out in collaboration between both authors. Author GCM conducted the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author UR designed the study. Both authors read and approved the final manuscript.

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ABSTRACT

Functional foods such as sweet cookies, *masala* cookies and *khakhra* were prepared by incorporating modified starch extracted from selected traditional rice varieties. The products were standardized by incorporating modified rice starch served as test product group and without incorporating modified rice starch served as control product group. The developed products such as sweet cookies, *masala* cookies and *khakhra* were stored up to 90 days at room temperature (25-30ºC) and relative humidity (40-60%). The packaging material used was 300 gauge low density polyethylene (LDPE). Samples from sweet cookies and *masala* cookies were drawn in triplicates for evaluation when fresh and after 15, 30, 45, and 60 days of storage, whereas samples from *khakhra* were drawn when fresh and after 30, 60, and 90 days of storage duration. The products were evaluated for their *In vitro* starch digestibility. In all the stored products, there was a significant ($p<0.05$) decreasing trend in rapidly digestible starch (RDS) and starch digestibility index (SDI), whereas increasing trend was observed in resistant starch (RS) and slowly digestible starch (SDS) as the storage period increased.

Keywords: In vitro starch digestibility; functional food; storage; modified rice starch.

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1. INTRODUCTION

Rice, being one of the primary dietary sources of carbohydrates worldwide, is of particular interest when assessing variability in starch digestibility. The digestion of starch is an important metabolic response and the rate and extent of starch digestibility are nutritionally important. Starch is classified into rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) according to the rate of glucose release and its absorption in the gastrointestinal tract [1]. Resistant starch as a functional ingredient demonstrates similar physiological benefits as dietary fibre in humans and thus is classified as fibre by AACC international [2]. RS is the starch that is resistant to enzymatic digestion, but is digested by the microbiota in the distal gastrointestinal tract [1]. RS has assumed importance in our daily diet due to its various beneficial health properties mostly mediated by short chain fatty acids produced during its fermentation in the large intestine [3,4]. In this sense, another starch fraction, slowly digestible starch (SDS), has received interest for its beneficial health effects [1,5,6,7]. The important feature of SDS is that it is digested slowly throughout the entire small intestine, which provides sustained glucose release with a low glycemic index and subsequently a slow and prolonged release of glucose. Therefore, SDS is considered to be beneficial for the dietary management of metabolic disorders [1,8,9,10] such as obesity, diabetes, and cardiovascular diseases [11]. The interest in developing functional foods has increased due to demanding foods that can improve the health and well-being of consumers. Obtaining rice starch with a high content of RS is of particular interest because it shows a slow rate of starch hydrolysis [12] and would therefore potentially provide rice with lower GI. Limited literature is available on the incorporation of modified rice starch into food products which are popularly consumed in India. Storage of foods is also a contributing factor to the changes in the available starch content of the product. Thus the objective of this study is to analyse effect of storage on *In vitro* starch digestibility of functional foods developed by incorporating modified rice starch.

2. MATERIALS AND METHODS

2.1 Standardization of Products by Incorporating Modified Rice Starch

Three traditional food products *viz.* sweet cookies*, masala cookies,*and *khakhra,* were developed by incorporating modified rice starch. The products contained either wheat flour (Control) or the wheat flour and modified rice starch (1:1, Test). The following paragraphs depict the preparation of above products.

2.1.1 Sweet cookies

Margarine was creamed with sugar, whole egg. Then added wheat flour plus modified rice starch and mixed thoroughly. Dough was rolled out to a 2 cm thickness on flat surface. Cookies were cut with a circular mould and placed on greased aluminium cookie tray. The cookies were baked at 160°C for 20 min in a baking oven. Baked cookies were allowed to cool down for 30 min and stored in a polyethylene covers.

2.1.2 Masala cookies

Wheat flour, modified rice starch, baking powder and salt were sieved together. The mixture was rubbed in fat, added green masala and sugar. The mixture was kneaded to a soft dough with curd. The dough was rolled in to a thin sheet and cookies were cut with biscuit cutter. Masala cookies were baked at 160°C for 30 min.

2.1.3 Khakhra

Wheat flour, resistant starch, salt and masala are mixed. Water was added and kneaded to make soft dough. The dough was rolled into small balls and were flattened. Khakhra were dry roasted on slow heat till it becomes crisp and light brown in colour. Khakhras were cooled and stored in polythene covers.

2.2 Storage Stability of Selected Food Products

The developed products such as sweet cookies, *masala* cookies and *khakhra* were stored up to 90 days at room temperature (25-30°C) and 40 to 60 per cent of relative humidity. The packaging material used was 300 gauge low density polyethylene (LDPE). Samples from sweet cookies and *masala* cookies were drawn in triplicates for evaluation of *in vitro* starch digestibility when fresh and after 15, 30, 45, and 60 days of storage, whereas samples from *khakhra* were drawn when fresh and after 30, 60, and 90 days of storage duration.

2.2.1 Starch fractions

The *In vitro* starch digestibility was analyzed in the sample by the revised method as described

by the Englyst et al. [1]. The various starch fractions (TS: total starch, RDS: rapidly digestible starch, SDS: slowly digestible starch, RS: resistant starch) were measured in modified rice starch incorporated food products. The starch was extracted after incubation with invertase, pancreatin and amyloglucosidase at 37°C in capped tubes immersed in a shaken water bath. Since foods normally require chewing they were minced by standard procedure, the incubation tubes contained glass balls for disrupting the food particles and guar gum was added to standardize the viscosity of the incubation mixture. A value for rapidly available glucose (RAG) was obtained as the glucose released within 20 min (G_{20}). A second measurement (G_{120}) was obtained as glucose released within 120 min incubation. A third measurement (total glucose; TG) was obtained by gelatinization of the starch in boiling water and treatment with 7 M KOH at 0°C, followed by complete enzymatic hydrolysis with amyloglucosidase. Resistant starch was measured as the starch remained unhydrolyzed after 120 min incubation. Free glucose (FG) was also determined by treating the sample with acetate buffer and placing the tube in water bath at 100 °C for 30 min. Simultaneous tests were run in a similar manner with glucose standard. A blank tube containing buffer, glass balls and guar gum was also included to correct for the glucose present in amyloglucosidase solution.

The values for TS, RDS, SDS and RS were calculated from the values of G_{20}, G_{120}, FG and TG as follows.

$$\mathrm{TS} = (\mathrm{TG} - \mathrm{FG}) \times 0.9 \qquad \mathrm{SDS} = (\mathrm{G}_{120} - \mathrm{G}_{20}) \times 0.9$$

$$\mathrm{RDS} = (\mathrm{G}_{20} - \mathrm{FG}) \times 0.9 \qquad \mathrm{RS} = (\mathrm{TG} - \mathrm{G}_{120}) \times 0.9$$

The relative rate of starch digestion was calculated as follows.

$$\mathrm{SDI} = \frac{\mathrm{RDS} \times 100}{\mathrm{TS}}$$

RAG = Free glucose + glucose from sucrose + glucose eleased within 20 min incubation. i.e., RAG = FG + glucose from sucrose + G_{20}.

2.3 Statistical Analyses

All the analyses were performed in triplicates. All data were analysed by two way ANOVA procedure and independent 't' test using SPSS software version 16.0. Differences were declared statistically significant when *P*= 0.05. Where significant differences were detected, the means were separated by Duncan's multiple range test (DMRT) at 5 % probability level using the MSTAT-C statistical package.

3. RESULTS AND DISCUSSION

3.1 Effect of Storage on *in vitro* Starch Digestibility of Products

Starch digestibility is known to vary among different starchy foods and has increasingly attracted interest in the context of non-insulin-dependent diabetes management [13]. Processed foods invariably undergo storage at moderate or low temperatures before consumption. Storage of foods is also a contributing factor to the changes in digestibility characteristics of starch-based products. The quantity of resistant starch (RS) formed, during processing/storage depends on the type of starch contained, severity of the processing conditions like degree of milling, temperature, freezing, drying, pH, moisture, number of heating/cooking/baking cycles adopted, condition of storage, the presence of fat or protein and the initial amylose to amylopectin ratio, etc. [14-19].

Therefore, effect of storage and product groups on *In vitro* starch digestibility of sweet cookies, *masala* cookies and *khakhra* were studied. The results of Tables 1 to 6 are discussed under the following paragraphs. The values are expressed as per cent of total starch with respect to dry matter in order to avoid the effect of moisture content on starch fraction results.

3.1.1 Sweet cookies

The *in vitro* starch digestibility results of the sweet cookies stored for different durations are presented in Table 1. With regard to control cookies, there were no significant differences observed between initial, 15 days, and 30 days storage duration in rapidly digestible starch (RDS), slowly digestible starch (SDS), resistant starch (RS) and starch digestibility index (SDI), however there were significant (*P*= .05) differences between the initial values and those at 45 days, with decrease in RDS from 40.85 (Initial) to 38.30 (45 days) per cent and SDI from 77.22 (Initial) to 72.70 (45 days) whereas the RS increased over this period from 2.03 (Initial) to 2.44 (45 days) per cent and SDS from

10.02 (Initial) to 11.94 (45 days) per cent. However, in total starch (TS) there was no clear trend and no significant differences were detected.

With regard to test cookies, significant (*P*= .05) decreasing trends were observed from 32.36 (Initial) to 27.65 (45 days) per cent in RDS and from 55.45 (Initial) to 47.39 (45 days) in SDI, whereas increasing trends were observed from 18.65 (Initial) to 22.61 (45 days) per cent in SDS and 7.35 (Initial) to 9.62 (45 days) per cent in RS. TS did not differ significantly during storage. Analysis of variance test indicated that, product groups, storage duration and interactions were found to have significant (*P*= .05) effect on all starch fractions studied except for TS.

Table 2 depicts the independent 't' test, which was performed to determine whether there is a statistically significant difference between the means of two product groups during storage with regard to starch fractions. Test cookies recorded significantly (*P*= .01) highest SDS, RS and TS content whereas control cookies were observed to be significantly highest in RDS and SDI at initial, 15 days, 30 days and 45 days storage duration.

3.1.2 Masala cookies

The *In vitro* starch digestibility results of the *masala* cookies stored for different durations are presented in Table 3. With regard to control cookies, significant (*P*= 0.05) differences were observed between the initial values and those at 45 days, with decrease in RDS from 32.87 (Initial) to 29.75 (60 days) per cent and SDI from 70.95 (Initial) to 64.21 (60 days) whereas, the SDS increased over this period from 11.53 (Initial) to 14.48 (60 days) per cent, RS from 1.92 (Initial) to 2.10 (60 days) per cent. However, in total starch (TS) there was no clear trend and no significant differences were detected.

With regard to test cookies, significant (*P*= .05) decreasing trends were observed from 25.45 (Initial) to 22.03 (60 days) per cent in RDS and from 48.70 (Initial) to 42.14 (60 days) in SDI. Further, increased trends were noticed from 20.17 (Initial) to 22.42 (60 days) per cent in SDS and 6.64 (Initial) to 7.82 (60 days) per cent in RS. TS did not differ significantly (*P*= .05) during storage. Analysis of variance test indicated that, product groups, storage duration and interactions were found to have significant (*P*= .05) effect on all starch fractions studied except for TS.

Table 4 depicts independent 't' test which was performed to determine whether there is a statistically significant difference between the means of two product groups during storage with regard to starch fractions. Test cookies recorded significantly (*P*= .01) highest SDS, RS and TS content, whereas control cookies were observed to be significantly highest in RDS and SDI at initial, 15 days, 30 days and 45 days storage duration.

3.1.3 Khakhra

The *In vitro* starch digestibility results of the *khakhra* stored for different durations are presented in Table 5. With regard to control *khakhra*, significant (*P*= .05) differences observed between the initial values and those at 90 days, with decrease in RDS from 43.60 (Initial) to 39.24 (90 days) per cent and SDI from 77.01 (Initial) to 69.64 (90 days) whereas, the SDS increased over this period from 11.44 (Initial) to 14.40 (90 days) per cent, RS from 1.58 (Initial) to 2.91 (90 days) per cent. However, in total starch (TS) there was no clear trend and no significant differences were detected.

With regard to test *khakhra*, significant (*P*= .05) decreasing trends were observed from 37.74 (Initial) to 29.32 (90 days) per cent in RDS and from 63.27 (Initial) to 49.16 (90 days) in SDI, whereas increasing trends were observed from 16.40 (Initial) to 23.14 (90 days) per cent in SDS and 5.51 (Initial) to 7.18 (90 days) per cent in RS. TS did not differ significantly during storage. Analysis of variance test indicated that, product groups, storage duration and interactions were found to have significant (*P*= .05) effect on all starch fractions studied except for TS.

Table 6 depicts independent 't' test which was performed to determine whether there is a statistically significant difference between the means of two product groups during storage with regard to starch fractions. Test *khakhra* recorded significantly (*P*= .01) highest SDS, RS and TS content whereas, control *khakhra* were observed to be significantly highest in RDS and SDI at initial, 15 days, 30 days and 45 days storage duration.

Table 1. ANOVA test for effect of storage and product groups on *In vitro* starch digestibility of Sweet cookies

Groups	Duration	Starch fractions (%)				
		RDS	SDS	RS	TS	SDI
Control	Initial	40.85 [a]	10.02 [f]	2.03 [g]	52.90 [b]	77.22 [a]
	15 days	40.32 [a]	10.24 [f]	2.10 [fg]	52.66 [b]	76.56 [a]
	30 days	40.30 [a]	10.29 [f]	2.13 [f]	52.72 [b]	76.45 [a]
	45 days	38.30 [b]	11.94 [e]	2.44 [e]	52.68 [b]	72.70 [b]
Test	Initial	32.36 [c]	18.65 [d]	7.35 [d]	58.36 [a]	55.45 [c]
	15 days	29.25 [d]	21.34 [c]	7.66 [c]	58.25 [a]	50.22 [d]
	30 days	27.97 [e]	21.84 [b]	8.56 [b]	58.37 [a]	47.92 [e]
	45 days	27.65 [e]	22.61 [a]	9.62 [a]	58.34 [a]	47.39 [e]
Groups (A)	F test	*	*	*	*	*
	SEm±	0.159	0.109	0.024	0.080	0.220
	CD at 5 %	0.440	0.302	0.067	0.221	0.610
Duration (D)	F test	*	*	*	NS	*
	SEm±	0.225	0.154	0.034	0.113	0.311
	CD at 5 %	0.623	0.426	0.095	-	0.863
AXD	F test	*	*	*	NS	*
	SEm±	0.318	0.218	0.048	0.159	0.440
	CD at 5 %	0.881	0.603	0.134	-	1.220

** Significant at 5 % level; [NS] Non significant Means in the same column followed by different superscript letters differ significantly*
RDS: Rapidly digestible starch;SDS: Slowly digestible starch; RS: Resistant starch; TS: Total starch; SDI: Starch digestibility index

Table 2. 't'-test for effect of storage between product groups on *In vitro* starch digestibility of sweet cookies

Starch fractions	Groups	Duration (Days)			
		Initial	15	30	45
A. Rapidly digestible starch (RDS)	Control	40.85	40.32	40.30	38.30
	Test	32.36	29.25	27.97	27.65
t-value		70.07**	46.56**	14.62**	66.36**
B. Slowly digestible starch (SDS)	Control	10.02	10.24	10.29	11.94
	Test	18.65	21.34	21.84	22.61
t-value		135.93**	237.79**	224.26**	17.56**
C. Resistant starch (RS)	Control	2.03	2.10	2.13	2.44
	Test	7.35	7.66	8.56	9.62

Starch fractions	Groups	Duration (Days)			
		Initial	15	30	45
t-value		67.90**	96.57**	99.37**	94.10**
D. Total starch (TS)	Control	52.91	52.67	52.71	52.68
	Test	58.36	58.25	58.37	58.34
t-value		35.17**	25.38**	16.21**	67.16**
E. Starch digestibility index (SDI)	Control	77.22	76.56	76.45	72.70
	Test	55.45	50.22	47.92	47.39
t-value		229.63**	123.38**	23.76**	112.75**

***Significant at 1% level*

Table 3. ANOVA test for effect of storage and product groups on *In vitro* starch digestibility of *masala cookies*

Groups	Duration	Starch fractions (%)				
		RDS	SDS	RS	TS	SDI
Control	Initial	32.87 ^{a}	11.53 ^{h}	1.92 ^{f}	46.32 ^{b}	70.95 ^{a}
	15 days	31.96 ^{b}	12.16 ^{g}	2.16 ^{f}	46.10 ^{b}	69.33 ^{b}
	45 days	29.78 ^{c}	14.36 ^{f}	2.13 ^{e}	46.27 ^{b}	64.37 ^{c}
	60 days	29.75 ^{c}	14.48 ^{e}	2.10 ^{e}	46.33 ^{b}	64.21 ^{c}
Test	Initial	25.45 ^{d}	20.17 ^{d}	6.64 ^{d}	52.26 ^{a}	48.70 ^{d}
	15 days	23.05 ^{e}	22.17 ^{c}	7.06 ^{c}	52.28 ^{a}	44.09 ^{e}
	45 days	22.44 ^{f}	22.31 ^{b}	7.56 ^{b}	52.31 ^{a}	42.90 ^{f}
	60 days	22.03 ^{f}	22.42 ^{a}	7.82 ^{a}	52.27 ^{a}	42.14 ^{g}
Groups (A)	F test	*	*	*	*	*
	SEm±	0.071	0.018	0.016	0.070	0.071
	CD at 5 %	0.198	0.051	0.044	0.193	0.196
Duration (D)	F test	*	*	*	NS	*
	SEm±	0.101	0.026	0.022	0.098	0.100
	CD at 5 %	0.279	0.072	0.062	-	0.277
AXD	F test	*	*	*	NS	*
	SEm±	0.143	0.037	0.032	0.139	0.141
	CD at 5 %	0.395	0.101	0.088	-	0.392

** Significant at 5 % level; ^{NS} Non significant Means in the same column followed by different superscript letters differ significantly;*
RDS: Rapidly digestible starch; SDS: Slowly digestible starch; RS: Resistant starch; TS: Total starch; SDI: Starch digestibility index

Table 4. 't'-test for effect of storage between product groups on *In vitro* starch digestibility of *masala* cookies

Starch fractions	Groups	Duration (Days)			
		Initial	15	45	60
A. Rapidly digestible starch (RDS)	Control	32.87	31.96	29.78	29.75
	Test	25.45	23.05	22.44	22.03
t-value		56.60**	26.49**	43.30**	141.21**
B. Slowly digestible starch (SDS)	Control	11.53	12.16	14.36	14.48
	Test	20.17	22.17	22.31	22.42
t-value		139.90**	156.07**	200.23**	201.32**
C. Resistant starch (RS)	Control	1.92	2.16	2.13	2.10
	Test	6.64	7.06	7.56	7.82
t-value		125.56**	75.54**	133.98**	138.20**
D. Total starch (TS)	Control	46.32	46.10	46.27	46.33
	Test	52.26	52.28	52.31	52.27
t-value		87.34**	19.30**	28.72**	96.59**
E. Starch digestibility index (SDI)	Control	70.95	69.33	64.37	64.21
	Test	48.70	44.09	42.90	42.14
t-value		105.27**	82.46**	243.26**	184.65**

***Significant at 1% level*

Table 5. ANOVA test for effect of storage and product groups on *in vitro* starch digestibility of *Khakhra*

Groups	Duration	Starch fractions (%)				
		RDS	SDS	RS	TS	SDI
Control	Initial	43.60 ^{a}	11.44 ^{h}	1.58 ^{h}	56.61 ^{b}	77.01 ^{a}
	30 days	42.04 ^{b}	12.13 ^{g}	2.48 ^{f}	56.65 ^{c}	75.00 ^{b}
	60 days	41.37 ^{c}	12.40 ^{f}	2.37 ^{g}	55.74 ^{c}	73.96 ^{c}
	90 days	39.24 ^{d}	14.40 ^{e}	2.91 ^{e}	56.55 ^{bc}	69.64 ^{d}
Fresh	Initial	37.74 ^{e}	16.40 ^{d}	5.51 ^{d}	59.66 ^{a}	63.27 ^{e}
	30 days	35.21 ^{f}	18.40 ^{c}	6.05 ^{c}	59.65 ^{a}	59.02 ^{f}
	60 days	32.48 ^{g}	20.34 ^{b}	6.59 ^{b}	59.41 ^{a}	54.67 ^{g}
	90 days	29.32 ^{h}	23.14 ^{a}	7.18 ^{a}	59.64 ^{a}	49.16 ^{h}
Groups (A)	F test	*	*	*	*	*
	SEm±	0.082	0.022	0.016	0.074	0.065
	CD at 5 %	0.228	0.062	0.044	0.204	0.181

Groups	Duration	Starch fractions (%)				
		RDS	SDS	RS	TS	SDI
Duration (D)	F test	*	*	*	NS	*
	SEm±	0.116	0.032	0.022	0.104	0.092
	CD at 5 %	0.322	0.088	0.062	-	0.256
AXD	F test	*	*	*	NS	*
	SEm±	0.164	0.045	0.032	0.147	0.130
	CD at 5 %	0.455	0.124	0.088	-	0.361

** Significant at 5 % level; ^{NS} Non significant Means in the same column followed by different superscript letters differ significantly*
RDS: Rapidly digestible starch; SDS: Slowly digestible starch; RS: Resistant starch; TS: Total starch;SDI: Starch digestibility index

Table 6. 't'-test for effect of storage between product groups on *in vitro* starch digestibility of *Khakhra*

Starch fractions	Products	Duration (Days)			
		Initial	30	60	90
A. Rapidly digestible starch (RDS)	Control	43.60	42.04	41.37	39.24
	Test	37.74	35.21	32.48	29.32
t-value		20.87**	42.26**	42.39**	38.30**
B. Slowly digestible starch (SDS)	Control	11.44	12.13	12.40	14.40
	Test	16.40	18.40	20.34	23.14
t-value		95.78**	73.29**	165.09**	145.50**
C. Resistant starch (RS)	Control	1.58	1.88	2.17	2.71
	Test	5.51	6.05	6.59	7.18
t-value		96.99**	97.53**	87.00**	97.80**
D. Total starch (TS)	Control	56.61	56.65	55.74	56.55
	Test	59.66	59.65	59.41	59.64
t-value		10.50**	47.82**	22.11**	13.46**
E. Starch digestibility index (SDI)	Control	77.01	75.00	73.96	69.64
	Test	63.27	59.02	54.67	49.16
t-value		105.98**	76.19**	91.24**	116.50**

***Significant at 1% level*

In all the stored products, there was a significant (*P*= .05) decreasing trend in RDS and SDI, whereas increasing trend was observed in RS and SDS as the storage period increased (Tables 1, 3 and 5). Analysis of variance test indicated that, product groups, storage duration and interactions were found to have significant (*P*= .05) effect on all starch fractions studied except for TS. All the test products contain appreciable amounts of RS and SDS ranging from 5.51 (*khakhra*) to 7.35 (sweet cookies) per cent and 16.40 (*khakhra*) to 20.17 (*masala* cookies) per cent respectively (Initial) and upon storage RS and SDS significantly (*P*= .05) increased ranging from 7.18 (*khakhra*) to 9.62 (sweet cookies) per cent and 22.42 (*masala* cookies) to 23.14 (*khakhra*) per cent respectively. This indicated that processing treatment and storage favours the formation of RS and SDS in these foods. During cooking starch granules are gelatinized and partly solubilized becoming available to digestive enzymes and no retrogradation took place. The formation of RS_3 which is retrograded amylose takes place within hrs after heating, during cooling period. It involves recrystalization of the amylose fraction (linear-(1,4)-α-D-glucose) and retrogradation of amylopectin (branched (1,4),(1,6)- α-D-glucose). The linear amylose molecules associate very easily and therefore retrograde easily than amylopectin [20].

In the present study, among the three products stored viz., test product groups of sweet cookies, *masala* cookies and *khakhra*, recorded significantly (*P*= .01) highest SDS (slowly digestible starch), RS (resistant starch) and TS (total starch) content, whereas control product groups were observed to be significantly highest in RDS (rapidly digestible starch) and SDI (starch digestibility index) at storage duration (Tables 2, 4, and 6). Products with high level of SDS and RS provide the nutritional and health benefits. Because these do not produce postprandial hyperglycemia and hyperinsulinemic spikes associated with the RDS consumption [6].

The slowdown of starch hydrolysis through storage is caused by recrystallization of previously gelatinized starch. Retrogradation of amylose is an irreversible process [21] and leads to the formation of an indigestible and physiologically important starch fraction which has been classified as resistant starch type 3 [1,22]. Retrogradation of amylopectin is a more complex phenomenon and depends largely on the botanical source, the structure and the storage conditions [23]. It has been stated that retrogradation of amylose reaches a limit after 2 days, whereas retrogradation of amylopectin continues until 30 to 40 days after gelatinization. Long-term storing and retrogradation processes, however, usually lead to sensory properties which are unacceptable for consumption [24]. Reduced enzyme susceptibility of recrystallized amylopectin was observed previously, e.g. by Eerlingen et al. [25] in the case of maize. Particle size and physical accessibility were also cited as factors reducing retrograded amylopectin enzyme susceptibility, aside from crystallinity. These factors might be explained in our study that, the samples which showed less RS and SDS content when analyzed immediately after cooking had a relative increase in RS and SDS formation on storage. Similar results have been reported in a study [19,26].

Several reports in the literature indicated the presence of RS in processed foods such as bakery foods [27] and cereal based foods [17,26,28,29]. Small changes in TS content of all the products was observed during storage but it was not significant ($p>0.05$). The availability of starch to enzyme action depends on physical and chemical changes in the starch structure during storage.

4. CONCLUSION

In all the stored products, there was a significant ($p<0.05$) decreasing trend in rapidly digestible starch (RDS) and starch digestibility index (SDI), whereas increasing trend was observed in RS and SDS as the storage period increased. The modified rice starch as source of resistant starch may have added benefit for individuals with diabetes requiring indigestible or slowly digestible carbohydrates. Hence, modification of rice starches to obtain functional properties and health benefits through processing methods is possible.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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