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Oral processing behavior of fat and fiber rich biscuits

Priyanka S, Moses JA and C Anandharamakrishnan

Abstract
The current study aimed to investigate the impact of *in-vivo* oral processing on various biscuit varieties such as high fat biscuits (HFA) and high fiber biscuits (HFB). Various *in-vivo* oral processing parameters such as mastication features (portion size, consumption time, and chew cycles), bolus properties (particle size distribution, and bolus moisture content) and time dependent parameters (saliva content and rate of incorporation of saliva) were studied. Further, temporal dominance of sensations (TDS) technique was carried out to identify and document the dominant oro-sensory perception during oral processing of biscuits. Biscuit varieties showed significant influence on various oral processing parameters; there was a pronounced relationship between the ingested portion size, composition, structural features and oral processing behavior of biscuit varieties. Structure, surface roughness, and composition such as presence of fat and fibre in biscuit varieties (HFA and HFB) has prominent effect on consumption time (16.92 s and 25.67 s) and chewing rate (1.44 chews/s and 1.09 chews/s) respectively. The D_{50} (mm) of the boluses of HFA and HFB ranged between 0.25 to 0.38 mm. The rate of saliva incorporation was relatively low for HFA compared to HFB. Furthermore, this study aids us in understanding the impact of food structure and composition on texture perception and oral destruction of foods. Thus, knowledge about oral processing helps in designing personalized smart foods with modified texture, composition and digestibility.

Keywords: Food oral processing, biscuits, mastication features, bolus properties, particle size

1. Introduction

Nowadays, consumers are more stringent about their snacking behaviour and the type of snack food they consume. Further, consumers are shifting towards the concept of healthy eating without compromising their taste and sensorial attribute of the product (Marangoni *et al*., 2019) [17]. Biscuit is one of the most popular snack food across the world (Theagarajan, Malur Narayanaswamy, Dutta, Moses, & Chinnaswamy, 2019; Zbib, Wooldridge, Ahmed, & Benlian, 2010) [33, 35]. Thus, in recent years lots of multinational food manufacturing companies are investing huge amount of money in research and development to develop healthy snack foods (Mellentin & Heasman, 2014) [18]. Consumers are preferring snack foods that are rich in fibre, protein and whole grains and those that have minimum /reduced amount of salt, sugar, fat, carbohydrates, and calories (Nielsen, 2014; Priyanka, S., Moses, J.A., & Anandharamakrishnan, 2019c) [19, 26].

Lot of researches are being done to develop new products (food structuring) with improved health benefits by choosing healthy ingredients, and processing methods to preserve and to retain its fullest nutritional and sensory properties. But, not much attention is being given to food destruction which happens upon ingestion food. Food destruction (food digestion) is a very long process which happens for several hours in the human digestive system (Roach, 2013) [29]. The digestion process happens in four different phases such as oral cavity (30 s -1 min), stomach (3-4 h), small intestine (3-5 h) and large intestine (10 -24 h). Though, very less time being spent by food in oral cavity its impact is much higher. It is the only stage of digestion where sensory perception, mechanical destruction, colloidal destabilisation and biochemical changes happens simultaneously (Chen, 2015) [5].

Oral processing of food greatly influences consumer liking of food as well as further digestion and absorption (Priyanka, S., Moses, J.A., & Anandharamakrishnan, 2019b) [25]. Apart from nutritional and functional benefits, sensory attributes directly link to consumer acceptance (Chen, 2014) [4]. Among sensory attributes, texture plays a vital role and is predominantly perceived during oral food processing. For instance, foods such as high fiber biscuits, are nutritionally rich, but may find challenges in the manufacturing process and in terms of consumer acceptance. Similar aspects explain the critical balance between nutrition and sensory attributes in the content of new product development (Priyanka, S., Moses, J.A., & Anandharamakrishnan, 2019a) [24].

Food structure and type of matrix plays significant role in oral processing (mastication behavior, lubrication, bolus properties, oral processing and swallowing time) (Bourne, 2002) [3]. Particle size distribution, average particle size and broadness of the size distribution depend on the type of the matrix, filler and individuals (Hutchings *et al*. 2011). Disintegration of food matrix during oral processing aid in interaction of released compounds with the enzymes present in the saliva (Duconseille *et al*., 2019) [9]. For instance, interaction of polyphenols with proline-rich protein elicit astringency taste and activity of alpha-amylase hydrolyze starch to glucose and dextrin. Moreover, the degree of interaction depends on the food microstructure and matrix. Further, disintegration of food matrix and hydration during oral processing aids in release of flavor and aroma components which will diffuse into saliva. (Repoux *et al*., 2012; Tarrega, Yven, Semon, & Salles, 2011) [27, 32].

Texture perception in the oral system is a complex phenomenon which is dependent on food structure (Prakash, Tan, & Chen, 2013) [22]. Texture and mouth feel influence consumer acceptability; thus, evaluation, measurement and quantification of texture is vital. Temporal dominance of sensation is relatively a novel dynamic technique which is used to evaluate the dynamic change in sensory perception during the entire oral processing events from first bite to swallowing. Thus, the sensory data obtained during the mastication of food aids us in understanding the relation between the texture perception and food structure in a better way. TDS aids us in representing the sequence of change of around 10 sensory attributes over the period of food consumption. This technique received a lot of research attention due is novelty, simplicity and cost effectiveness (Di Monaco, Su, Masi, & Cavella, 2014) [7].

Thus, the main objective of present study is to investigate the effect of food composition, structure and texture of two varieties of biscuits rich in fat (HFA) and fiber (HFB) on various oral processing parameters and temporal dominance of sensation.

2. Materials and Methods

2.1 Samples

Biscuit varieties such as high fat biscuits (HFA) and high fiber biscuits (HFB) used in the current study was procured from the local supermarket market at Thanjavur, Tamil Nadu.

2.2 Selection of subjects

The study was conducted using six human subjects (3 female and 3 male) aged between 20-35 years. The subjects were thoroughly screened for their dental conditions, food allergies, normal taste, smell capabilities and dysphagia. All subjects gave their written consent to take part in the oral study. The oral processing sessions were conducted during mid-morning (10.00-11.30 am) or mid-evening (4.00-5.30 pm) for each subjects individually.

2.3 Oral processing experimental approach

Each subject was presented with pre-defined amount of biscuit samples in a cup and they were instructed to consume as they would naturally do. The average bite size for biscuit varieties were calculated. Standardized portion size of biscuit samples were provided for the determination of various other oral processing parameters. The subjects were monitored during the entire oral processing session to calculate number of chews, number of swallows and consumption time.

2.4 Texture analysis

Texture of biscuit samples was analyzed using Texture Analyser (TA.HD. Plus; Stable Micro systems, Godalming, UK). Hardness of biscuits was measured by snap test employing three point bent Rig. The samples were rested on two supporting beams spread at a distance of 2.5 cm. Another beam connected to moving part was brought down to break the biscuits at a crosshead speed of 10 mm/min and with load cell of 30 kg. Care was taken to see that the point of contact was equivalent from both the supporting beams. The peak force (N) at break, representing hardness of the biscuits were recorded.

2.5 Temporal dominance analysis

TDS analysis was performed by 10 semi-trained panel members for both texture and flavor perceptions. Texture-TDS (T-TDS) and Flavor-TDS (F-TDS) analysis was performed separately for both the biscuit varieties (Rizo *et al*., 2019) [28]. Textural attributes such as hardness, dryness, crispiness, grittiness, powderiness, smoothness, pastiness and sticky on teeth; and flavor attributes such as floury, nutty, fatty, sweet, earthy and salty were picked accordingly in order to balance the sensorial attributes of both the biscuit varieties. Preliminary evaluations were conducted for sensory panelists in order to familiarize with the various above-listed sensory attributes. The panelists were asked to mark the most dominant sensation at the particular time. They were given the liberty to choose a single attributes any number of times and allowed not to select an attribute as dominant. TDS analysis for both texture and flavor commences once the first bite is taken (timer starts), dominant sensation was analyzed for every 3 seconds and session stopped once the sample was fully consumed (timer stops), mostly ranged from 0 to 30 seconds. Further, in the TDS plot two horizontal lines such as chance and significance level were included. The chance and significance level were calculated using following equations (1) and (2) (Laguna, Varela, Salvador, & Fiszman, 2013) [15].

$$P_0 = 1/P \quad (1)$$

$$P_S = P_0 + 1.645\sqrt{P_0(1 - P_0)/n} \quad (2)$$

Where, P_0 is chance limit
P is the number of attributes
P_s is significance limit of TDS curve (α=0.05)
n is number of trials

TDS curves which is rising from chance level to significance level and above are accepted as consistent attributes among panelists.

2.6 Determination of Mastication features

Various mastication features such as chewing cycle duration, chewing rate, eating rate and calorie velocity were calculated based on the formulas given in Eq (3),(4) and (5) (Aguayo-Mendoza *et al*., 2019) [1] and Eq (6) (Oladiran, Emmambux, & de Kock, 2018) [20].

$$Chewing\ cycle\ duration\ (s) = Total\ consumption\ time\ / Number\ of\ chews \quad (3)$$
$$Chewing\ rate\ (chews/s) = Number\ of\ chews / Total\ consumption\ time \quad (4)$$
$$Eating\ rate\ (g/s) = Weight\ of\ food\ consumed\ / Total\ consumption\ time \quad (5)$$
$$Calorie\ velocity\ (kcal\ g/s) = Eating\ rate * Energy\ density \quad (6)$$

2.7 Determination of bolus properties

The subjects were advised to expectorate the bolus at swallow able consistency and at specific time intervals such as 5 s, 10 s, 15 s, 20 s, 25 s, and 30 s. The collected bolus was used for determination of various bolus properties such as moisture content, solid loss percentage, amount of saliva incorporated and rate of saliva incorporation using the formulas given in Eq (7), (8), (9) and (10) (van Eck *et al*., 2018) [34].

$$Moisture\ content\ of\ boli/food(\%) = Initial\ wt - final\ wt / Initial\ wt * 100 \quad (7)$$
Solid loss (%)=(Dry matter wt of food-Dry matter wt of bolus)/(Dry matter wt of food)*100 (8)
$$Saliva\ incorporation\ (g/g\ dry\ wt) = Moisture\ n^{th}\ (s) / Moisture\ at\ 0^{th}\ (s) \quad (9)$$
$$Rate\ of\ saliva\ incorporation\ (g/s) = Saliva\ incorporation\ / Time \quad (10)$$

2.8 Determination of particle size/distribution

The expectorated bolus of various subjects was thoroughly washed with running water over 0.037 mm sieve to remove adhering saliva (Peyron, Mishellany, & Woda, 2004) [21]. The washed bolus was spread on to a petri plate and images were captured. The captured images were converted to greyscale and the average particle size (D_{50}) of the bolus was measured using Digimizer Version 4.3.1, (VC 2005–2014, MedCalc Software) (Reddy *et al.*, 2019) [23]. For determination of particle size distribution and average particle size (D_{50}) of the bolus using sieve analysis, the washed bolus was dispensed from the top of the stacked sieves with apertures of 4, 2.8, 2 0.85, 0.5, 0.3, 0.18, 0.106, 0.063 mm (Peyron *et al*., 2004) [21]. Portions remaining on each sieves were weighed and percentage particle size distribution of bolus was calculated.

2.9 Rheological behavior

Viscosity evaluation of the expectorated bolus was performed with Rheometer 52 (MCR 52, Anton Paar, Graz, Austria). The viscosities were recorded as a function of shear rate ranging from 0.1 s^{-1} to 100 s^{-1}. The method used by Aguayo-Mendoza *et al*.(2019) [1] was followed to fit Power law ($\eta = K\ \dot{\gamma}^{n-1}$) to the flow curves, in order to quantify consistency ‘K’ and flow behavior index ‘n’. All measurements were done in triplicate.

2.10 Statistical analysis

Experimental results were statistically analyzed using Paired Comparison T-test using SPSS statistics v. 25 (IBM Inc., Armonk, NY, USA). All experiments were performed in triplicates and results were expressed as mean ± standard deviation. The significance was established and probability level of $p \leq 0.05$ was considered as significant.

3. Results and discussion

3.1 Texture analysis

Hardness values of the selected biscuit varieties HFA and HFB were 16.29 ± 0.14 N and 17.52 ± 0.38 N, respectively. Hardness (maximum force required to break) of high fiber biscuits (HFB) were significantly higher than high fat biscuits (HFA). Similar results were also observed by (Laguna *et al*., 2013) [15]. The major reasons for higher hardness of high fiber biscuit is due to its lesser fat content which will aid in higher hydration of gluten present in flour resulting in a hard and cohesive dough subsequently yields biscuits with hard texture (Ghotra, Dyal, & Narine, 2002) [13]. The proximate composition and hardness of the biscuit varieties are presented in Table. 1.

3.2 Temporal dominance analysis

T-TDS and F-TDS was determined for both the biscuit varieties and presented in Fig. 1, Fig. 2, Fig.3, and Fig. 4, respectively.

3.2.1 T-TDS

The dominant texture sensation of both the biscuit varieties plotted in T-TDS showed significant variations. Hardness was the sole T-TDS for both the biscuits such as HFA and HFB during the initial stage of oral processing such as first bite (0 s) (Laguna *et al*., 2013; Rizo *et al*., 2019) [15, 28]. In case of HFA during the initial stage (0-9 s) hardness, crispiness and grittiness are the dominant sensation perceived by the panelists. However, in case of HFB the dominant sensations were hardness followed by dryness and crispiness during the initial stage (0-9s).

In case of HFA, dryness mouthfeel during initial chewing (3 s) could possibly be due to the friction between food particles and soft parts of oral cavity before saliva incorporation. Dryness sensation is the second dominant sensation in HFB which is due the presence of rough fiber particles which absorb the saliva quickly. Crispiness is the second dominant sensation after hardness in case of HFA which is due the presence of fat which interrupts the gluten network (Laguna *et al*., 2013) [15].

During the mid-stage (9-21 s) of oral process temporal dominance parameters like grittiness, Powderiness and smoothness were dominant in case of both the biscuit varieties. However, smoothness is the most dominant sensation in case of HFA which is due to saliva incorporation and extra lubricating nature of fat (Foster *et al*., 2011) [11]. Whereas, in HFB both grittiness and Powderiness were most dominant followed by smoothness, which is due the presence of lot of fibrous particle in oral cavity upon chewing the HFB. Pastiness and sticky on teeth are the dominant sensation at the final stage (21-30 s) of oral mastication of HFA. But, in case of HFB pastiness is not a dominant sensation rather, sticky on teeth is most dominant followed by smoothness. However, sticky on teeth is the most dominant for both HFA and HFB at the final stage of oral processing (Rosenthal & Pang, 2018) [31].

3.2.2 F-TDS

The F-TDS results showed that floury (0-6 s), nutty (0-12 s), fatty (6-21 s) and sweet (12-24 s) are the most significantly dominant flavor sensation in case of HFA. In case of HFB, the significantly dominant flavor sensations are floury (0-9 s), salty (3-30 s) and earthy (6-30 s). Salty and earthy are more persistent flavor sensation in case of HFB, whereas nutty and fatty are more dominant in case of HFA, as it is perceived by panelists over entire oral processing period. Flavor sensations are less complex and perceived comparatively lesser than texture during oral processing (Rizo *et al*., 2019) [28].

3.3 Mastication behavior

Various mastication parameters such as average bite size, chew cycles, consumption time, chewing cycle duration, chewing rate, eating rate and calorie velocities were studied to investigate the influence of fat and fiber in oral processing of biscuits and the results are illustrated in (Table 2). Various mastication features like chew cycles, number of swallows, chew cycle duration, and chewing rate are not significantly different in case of HFA and HFB. Average bite of HFA and HFB was 3.18 ± 0.05 g and 3.00 ± 0.02 g, respectively and they are significantly different from each other.

Number of chews of HFA and HFB is 24.33 ± 3.06 and 27.67 ± 2.52, respectively and there is no significant between each other. The main reason for this could be the existence of extreme differences between human subjects. The consumption time of HFB is significantly higher from HFA. The reason for higher consumption time and chew cycles of HFB is the presence of high amount fiber and hardness which requires longer time of mastication to reduce the particle size and to attain optimum lubrication which is necessary to reach a swallowable consistency (Foster, Woda, & Peyron, 2006; Oladiran *et al*., 2018) [12, 20]. Further, the presence of higher amount of fat provides extra lubrication and it is the chief reason for the lower consumption time and chew cycles of HFA biscuits to attain swallowable bolus consistency (Foster *et al*., 2011) [11].

Chew cycle duration and chewing rate of both types of biscuits such as HFA and HFB is not significantly different from each other. The chew cycle duration of HFB is 0.94 ± 0.16 s significantly higher and chewing rate is 1.09 ± 0.17 chews/s which is predominantly lower than that of previously observed values for chewable foods which is around 0.7 s and 1.4 chew/s, respectively. The reason for this behavior of HFB could be due to the presence of fiber and high viscous nature of bolus. The chew cycle duration and chewing rate of HFA are 0.70 ± 0.09 and 1.44 ± 0.20, respectively. These values are consistent with previous reports (Aguayo-Mendoza *et al*., 2019; Farooq & Sazonov, 2016) [1, 10].

Eating rate and calorie velocity of both the biscuits are positively correlated and significantly different from each other. The eating rate of HFA and HFB are 0.19 ± 0.01 g/s and 0.12 ±0.01 g/s, respectively. Eating rate depends on portion size and consumption time which is predominantly depend on the structural feature, physicochemical properties such as texture, rheology and chemical composition of the food product (Aguayo-Mendoza *et al*., 2019) [1]. Thus, presence of high fat and no fiber in HFA and high fiber in HFB greatly affects the mastication behavior. The calorie velocity of HFA is 0.95 ± 0.07 Kcal s/g is significantly greater than HFB which is 0.58 ± 0.06 Kcal s/g. The prime reason for this could be lower calorific value and eating rate of HFB compared to HFA.

3.4 Bolus properties

Bolus properties such as moisture content, average particle size, saliva incorporation and solid loss were determined for each bolus (Table 2). Further, time-dependent parameters like saliva content and rate of saliva incorporation were calculated from moisture content data of expectorated bolus samples at various time intervals. Bolus appearance of both the varieties of biscuits are presented in Fig. 5 and Fig. 6.

3.4.1 Moisture content of biscuits and bolus (%)

Moisture content of HFA and HFB were 2.21 ± 0.01 % and 2.4 ± 0.01 %, respectively and they are significantly different from each other. Moisture content was measured for boluses expectorated at the swallowable point and at various time intervals (5 s, 10 s, 15 s, 20 s, 25 s, and 30 s and were found to be significantly different from each other.

3.4.2 Saliva incorporation (g/g dry wt)

The amount of saliva incorporated during the oral processing of biscuits to develop a bolus with swallowable consistency differs significantly among the biscuit varieties. The amount of saliva incorporated in HFA and HFB were 51.45 ± 0.13 *g/g dry wt* and 54.57 ± 0.43 *g/g dry wt*, respectively. Saliva incorporated into HFB during oral processing to achieve a swallowable consistency was significantly higher than HFA. This could possibly be due to the fiber content and dry and hard texture of the HFB biscuit which requires longer chewing time and excessive lubrication with saliva to make it swallowable (Laguna *et al*., 2013) [15].

3.4.3 Solid loss (%)

Solid loss of HFA was significantly higher than HFB. The increased solid loss of HFA is due to the less viscous nature of bolus due the presence of fat which provides excessive lubrication to the bolus. Solid loss of HFA and HFB are 51.04 ±0.39 % and 46.44 ± 0.29 %, respectively. Further, the lesser solid loss in case of HFB is due to higher viscous nature of bolus due the presence of fiber which absorbs saliva and binds the bolus particles tightly together. These results infer that various factors like amount of saliva incorporated, number of chews and consumption time have considerable effect on solid loss.

3.4.4 Time based saliva content and rate of saliva incorporation

Moisture content of the bolus at various time intervals (5 s, 10 s, 15 s, 20 s, 25 s, and 30 s) were analyzed to find out time based parameters such as saliva content and rate of saliva incorporation. Saliva incorporation into HFA was lesser compared to that of HFB over the entire oral processing period. In case of both the biscuit varieties the amount of saliva incorporated was highest at fifth second, following a decreasing pattern with increase in time. The highest rate of saliva incorporation was found to be at the initial stage of mastication (fifth second). Similar trends have been shown by van Eck *et al.* (2018) [34]. Rate of saliva incorporation gradually decreases as the need for mastication decreases. Rate of saliva incorporation for HFB and HFA was 0.40 g/s. Rate of saliva incorporation and saliva content of bolus at various time interval is presented in Fig. 7.

3.5 Particle size analysis of boluses

Average particle size or D_{50} (mm) was found for the expectorated bolus of both the biscuit varieties (HFA and HFB) using sieve analysis and image analysis showed similar trends and they were not significantly different from each other. Average particle size of HFA and HFB using sieve were 0.34 ± 0.04 mm and 0.26 ± 0.03 mm; using image analysis were 0.38 ± 0.03 mm and 0.25 ± 0.04, mm respectively. The major reason for higher particle size of HFA could be due to agglomeration of biscuit particles due incorporation of saliva (Rodrigues, Young, James, & Morgenstern, 2014) [30]. Further, the presence of fiber in HFB is the predominant reason for the lesser particles size of bolus. Since, fibers are mostly insoluble in nature and hinders the agglomeration of smaller particles during oral processing (Alam *et al*., 2019) [2]. Further, harder food requires higher mastication time and chew cycle which results in smaller size particles in bolus (de Lavergne, van de Velde, & Stieger, 2017) [6]. The particle size distribution curves of the both the biscuit varieties is presented in Fig. 8.

3.6 Rheological behavior of boluses

Power law was fitted to the obtained data to determine consistency K (Pas), flow behavior index n and R^2 (Table 3). The expectorated biscuit boluses showed viscoelastic shear thinning behavior (n < 1) (Hadde & Chen, 2019) [14]. The flow behavior index n of HFA and HFB was 0.348 and 0.216, respectively and they are significantly different from each other. Further, K value of HFA and HFB was 151.43 Pas and 1009.1 Pas, respectively and they are significantly different from each other. K value of the expectorated greatly depends on viscosity of the bolus and there is positive correlation between K value and viscosity (Diamante & Umemoto, 2015) [8]. K value of HFB is significantly higher than HFA due to high water holding capacity of fiber which increases the viscosity of expectorated bolus (Leon, Aguilera, & Park, 2019) [16]. The graph between viscosity and shear rate is illustrated in Fig. 9.

Table 1: Physiochemical properties of biscuits varieties

Biscuit varieties	Proximate composition						Textural property
	Carbohydrates	Sugar	Proteins	Fat	Fiber	Energy	Hardness (N)
High fat biscuit (HFA)	65 g	22 g	7 g	24 g	-	504 kcal	16.29 ± 0.14^b
High fiber biscuit (HFB)	68 g	14.5 g	8 g	21 g	6 g	493 kcal	17.52 ± 0.38^a

Note: Means ± standard deviations are from triplicate analysis, means within same column denoted with different alphabets are significantly different ($P \leq 0.05$) from each other for individual measured parameters.

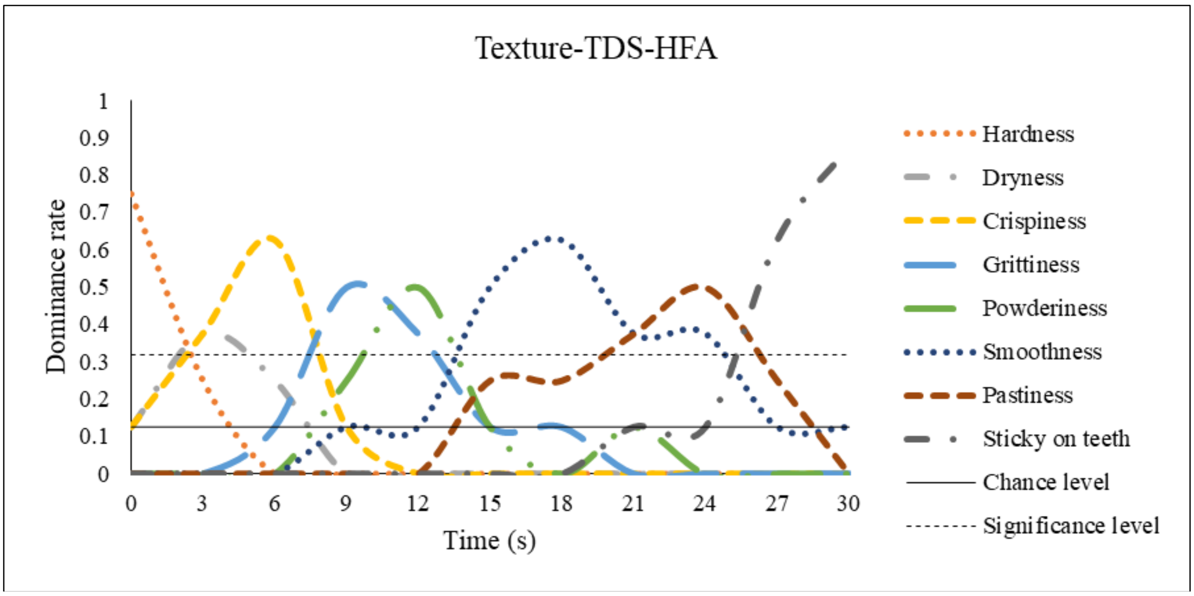

Fig 1: TDS curves of textural attributes of fat rich biscuits

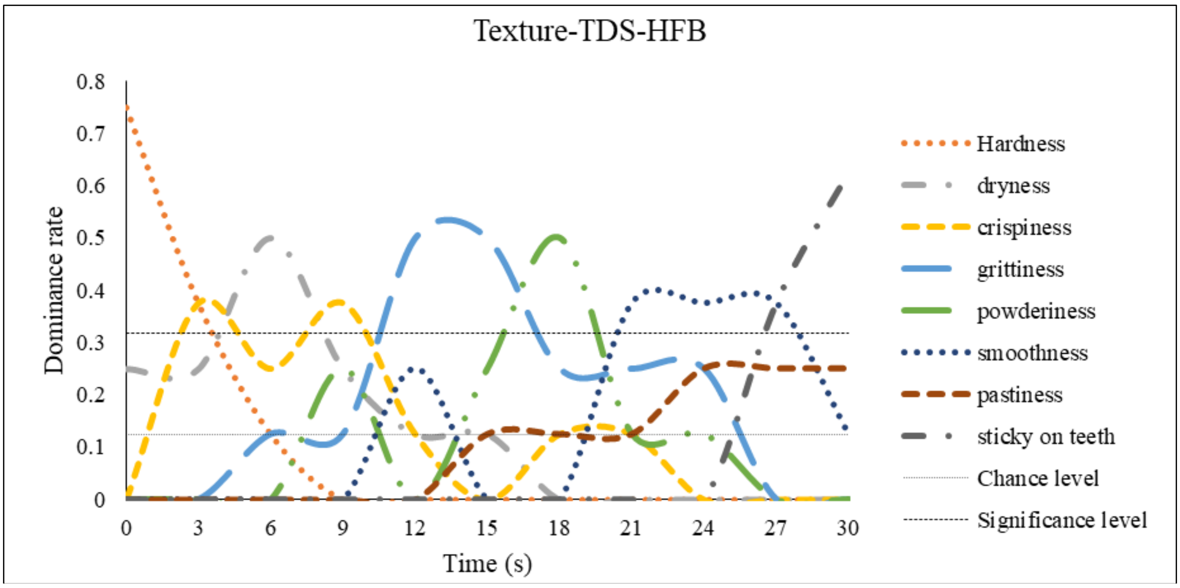

Fig 2: TDS curves of textural attributes of fiber rich biscuits

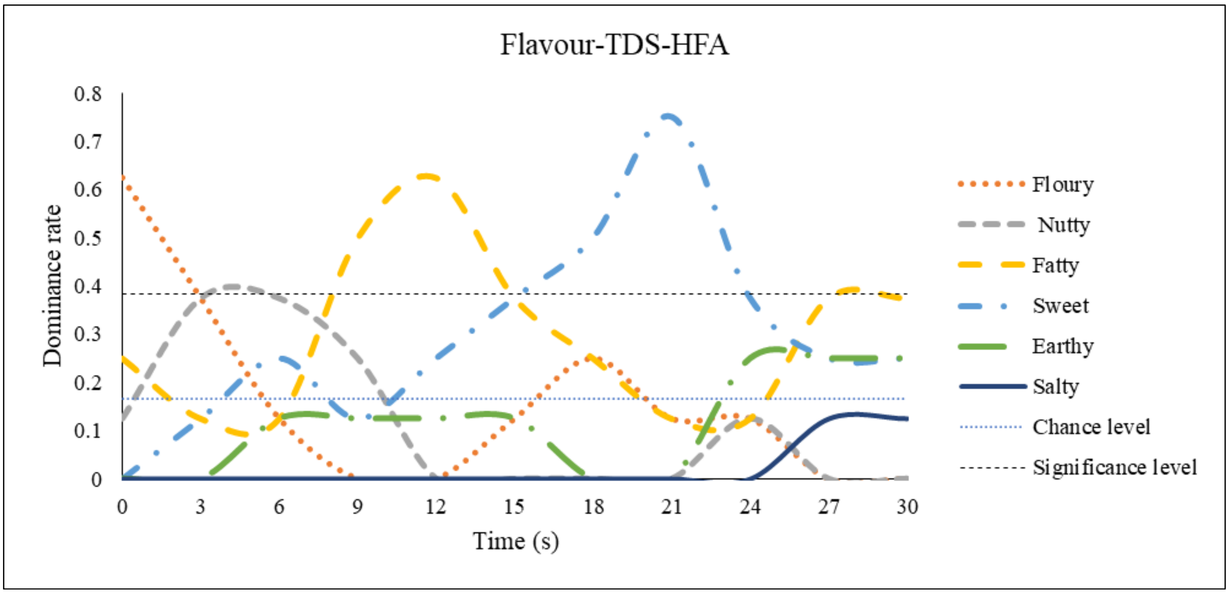

Fig 3: TDS curves of flavor attributes of fat rich biscuits

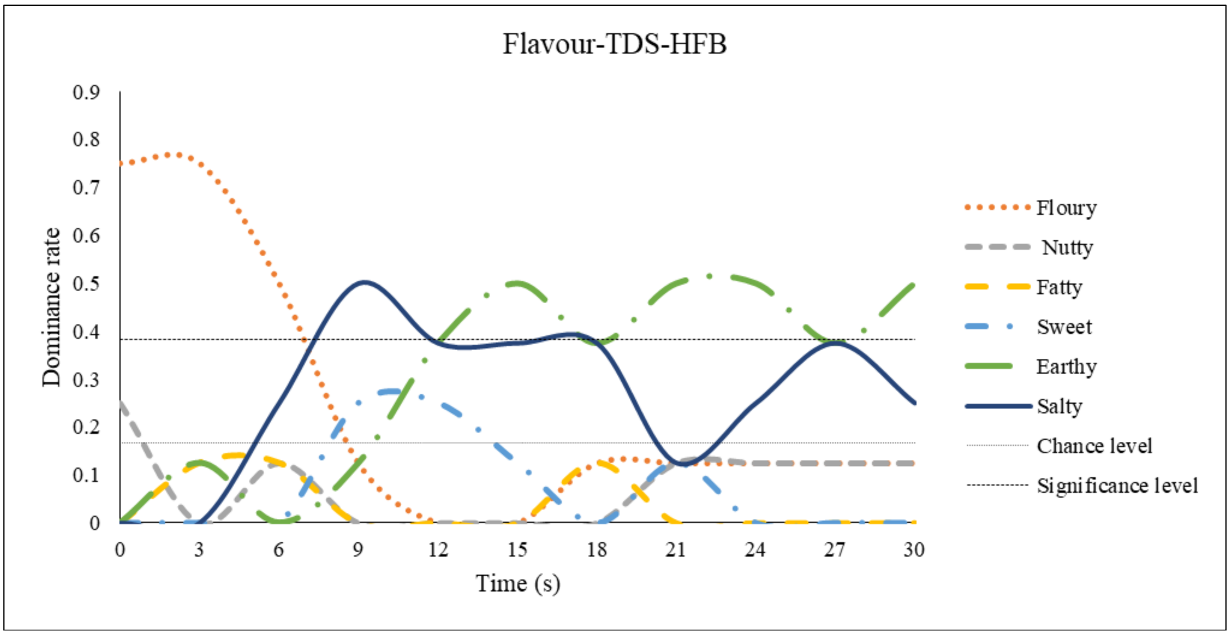

Fig 4: TDS curves of flavor attributes of fiber rich biscuits

Table 2: Mastication features and bolus properties of various biscuit varieties

Mastication features	Biscuit varieties	
	High fat biscuits (HFA)	High fibre biscuits (HFB)
Average bite size (g)	3.18 ± 0.05^{a}	3.00±0.02^{b}
Chew cycles (No's)	24.33±3.06^{a}	27.67±2.52^{a}
Consumption time (s)	16.92±1.62^{a}	25.67±2.52^{b}
No of swallows	3.02±0.88^{a}	3.21±0.85^{a}
Chewing duration (s)	0.70±0.09^{a}	0.94±0.16^{a}
Chewing rate (chew/s)	1.44±0.20^{a}	1.09±0.17^{a}
Eating rate (g/s)	0.19±0.01^{a}	0.12±0.01^{b}
Calorie velocity (kcal s/g)	0.95±0.07^{a}	0.58±0.06^{b}
Bolus properties	**Biscuits varieties**	
	High fat biscuits (HFA)	**High fibre biscuits (HFB)**
Moisture content of biscuits	2.21±0.01^{a}	2.4±0.01^{b}
Moisture (% db)	51.45±0.13^{a}	54.57±0.43^{b}
Saliva incorporation (g/g dry wt)	1.04±0.02^{a}	1.21±0.02^{b}
Solid loss (%)	51.40±0.39^{a}	46.44±0.29^{b}
Average particle size (mm)	0.34±0.04^{a}	0.26±0.03^{a}
D_{50} (mm)	0.38±0.03^{a}	0.25±0.04^{a}

Note: Means ± standard deviations are from triplicate analysis, means within same column denoted with different alphabets are significantly different ($P \leq 0.05$) from each other for individual measured parameters.

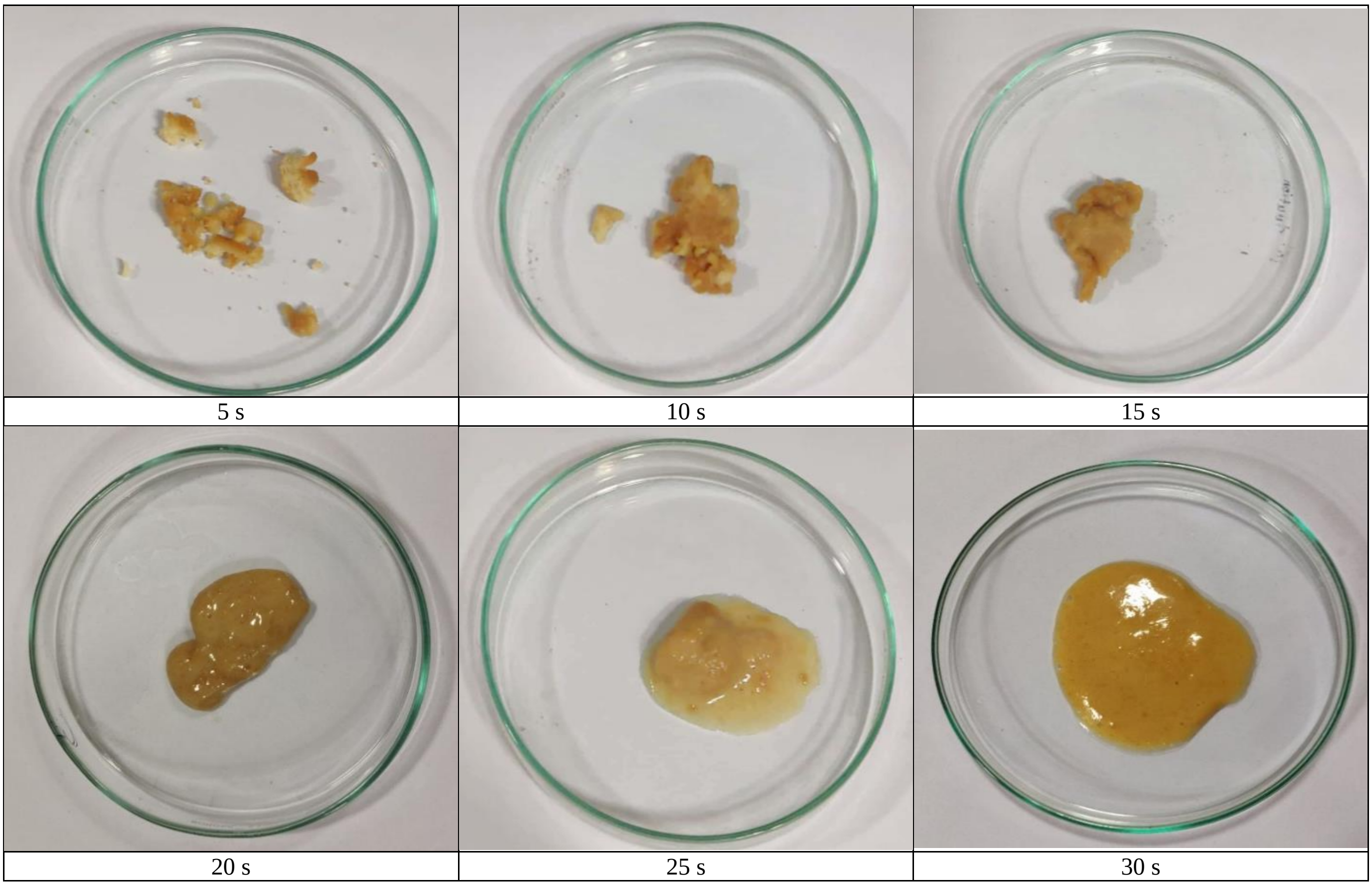

Fig 5: Bolus appearance of (HFA) at different time intervals

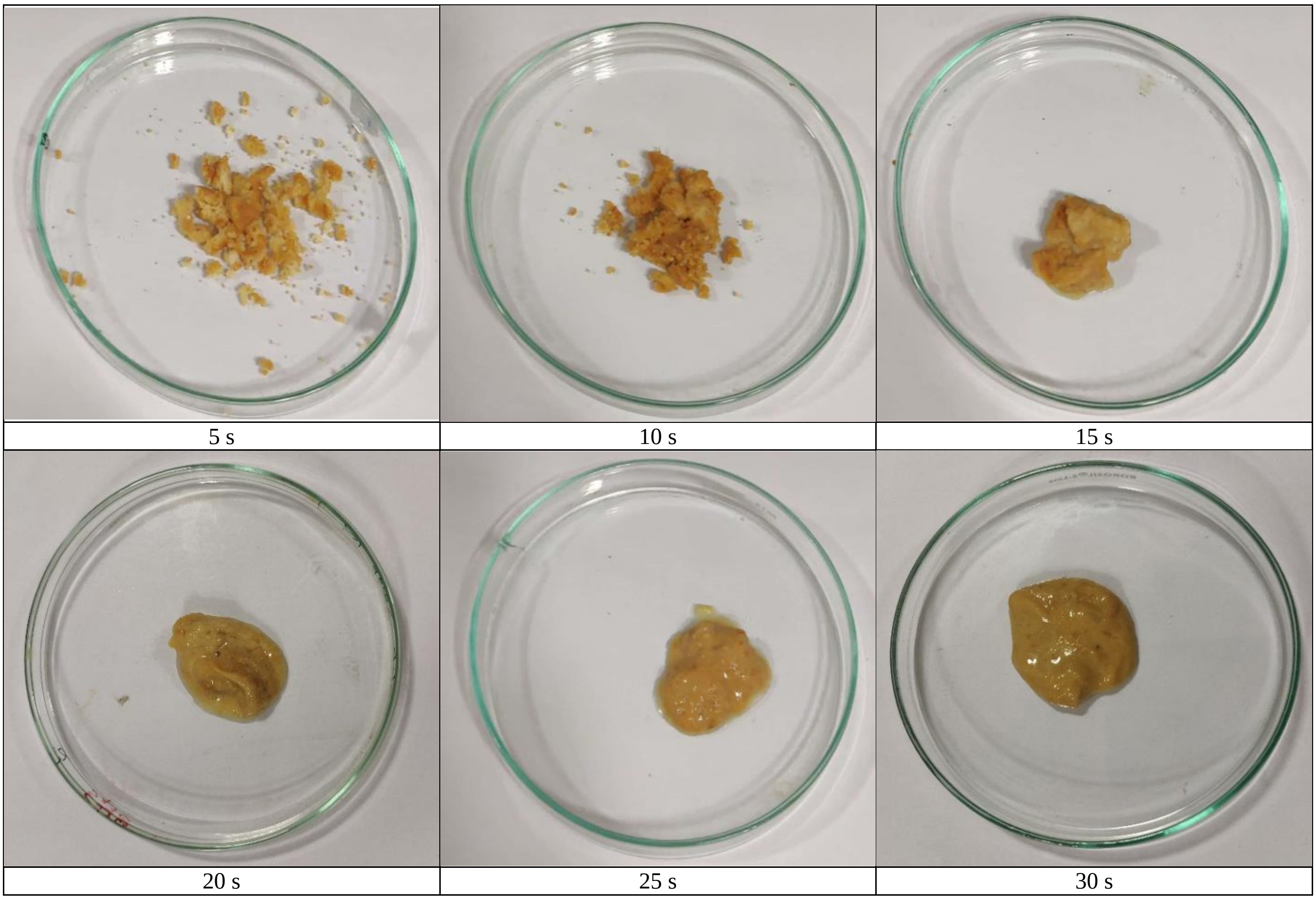

Fig 6: Bolus appearance of (HFB) at different time intervals

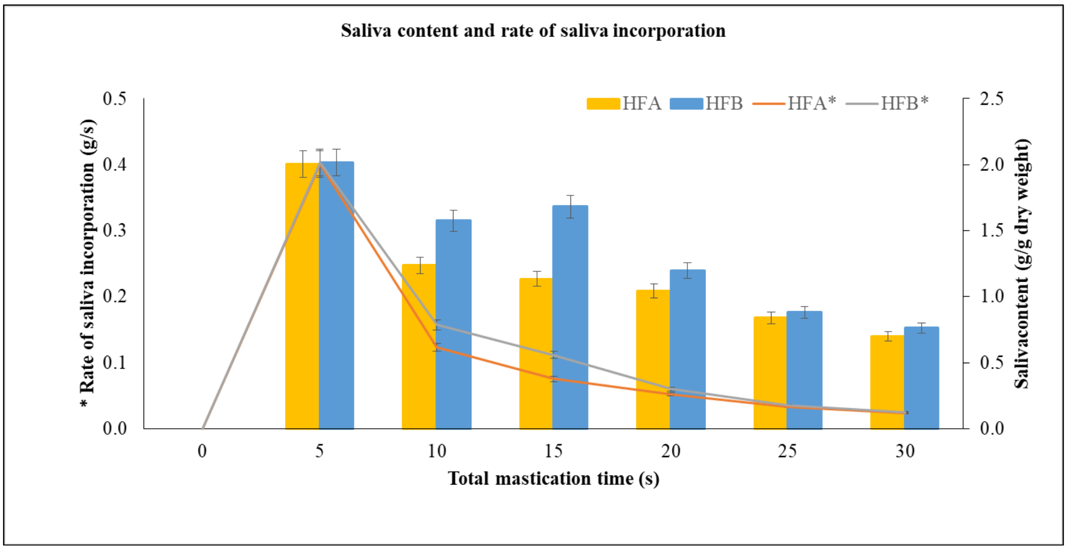

Fig 7: Saliva content & rate of saliva incorporation of orally processed boluses of fat and fiber rich biscuit varieties

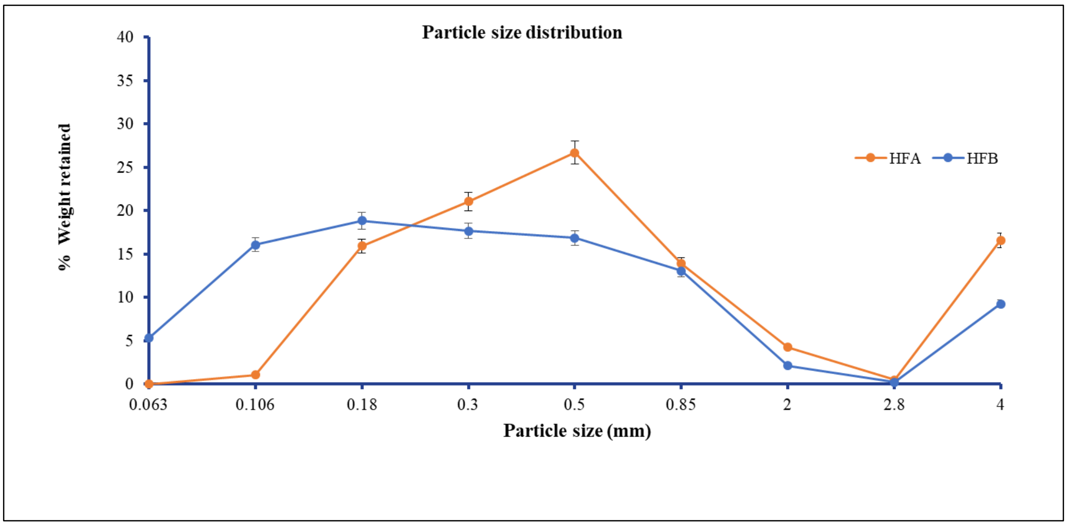

Fig 8: Particle size distribution of orally processed boluses of fat and fiber rich biscuit varieties

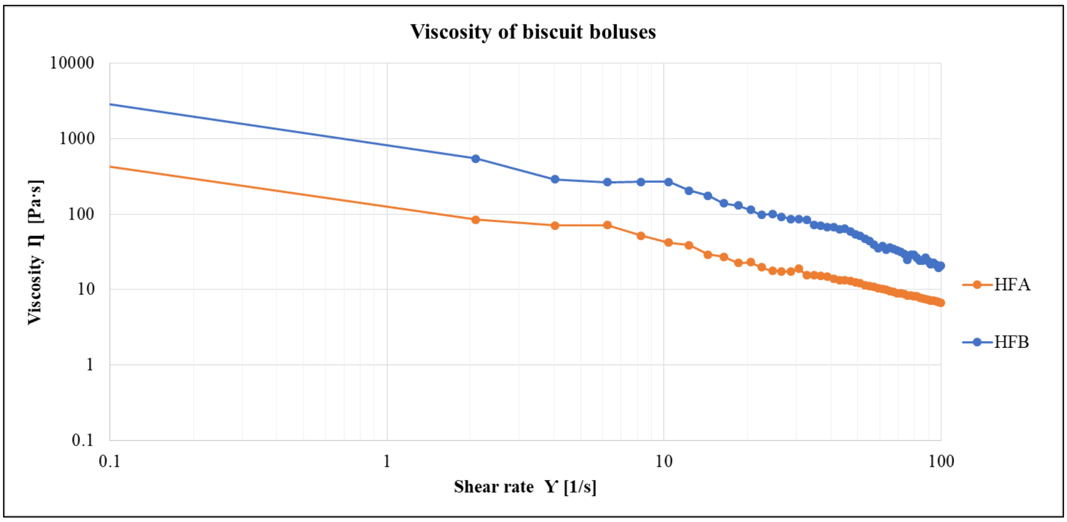

Fig 9: Shear thinning behavior of orally processed boluses of fat and fiber rich biscuit varieties

Table 3: Consistency (K) and flow behavior index (n) of selected Indian rice varieties

Biscuit varieties	Consistency (K, Pas)	Flow behavior index (n)	R^2
High fat biscuit (HFA)	151.43 ± 0.28 [a]	0.348 ± 0.001[a]	0.9726
High fiber biscuit (HFB)	1009.1 ± 0.31[b]	0.216 ± 0.001[b]	0.9423

Note: Means ± standard deviations are from triplicate analysis, means within same column denoted with different alphabets are significantly different ($P \leq 0.05$) from each other for individual measured parameters.

4. Conclusion

This study concludes that mastication and bolus properties of both the biscuit varieties are greatly influenced by textural property (hardness) and their composition i.e. presence of fat and fiber. Further, mastication behavior of subjects significantly affects various oral processing parameters such as portion size, number of chews and consumption time. Nevertheless, in case of bolus properties such as solid loss, average particle size, saliva content and rate of saliva incorporation, exhibited significant variation among biscuit varieties. Temporal dominance of sensation of both the biscuit varieties was very dynamic and showed significant dominance of various textural attributes over various time period. Texture- TDS of both the biscuits was highly dominated by hardness and crispiness during the initial stage (0-9 s). In the middle stage (9-21 s), HFA and HFB was significantly dominated by smoothness and grittiness and powderiness, respectively. Pastiness and sticky on teeth are the dominant temporal sensation for both the biscuit varieties during the final stage (21- 30 s). Flavor-TDS of HFA and HFB were significantly dominated by nutty and fatty and salty and earthy, respectively. TDS is greatly dependent on the composition and structure of foods. Average particle size D_{50} (mm) and consistency value (K) of HFB is higher than HFA, it would have significant effects on the rate of gastric digestion and starch hydrolysis. Further, research has to be carried out to find the effect of oral processing on gastric digestion, absorption and GI.

5. References

1. Aguayo-Mendoza MG, Ketel EC, van der Linden E, Forde CG, Piqueras-Fiszman B, Stieger M. Oral processing behavior of drinkable, spoonable and chewable foods is primarily determined by rheological and mechanical food properties. Food Quality and Preference. 2019; 71:87-95.
2. Alam SA, Pentikäinen S, Närväinen J, Katina K, Poutanen K, Sozer N. The effect of structure and texture on the breakdown pattern during mastication and impacts on *in vitro* starch digestibility of high fibre rye extrudates. Food & Function, 2019.
3. Bourne M. Food texture and viscosity: concept and measurement. Elsevier, 2002.
4. Chen J. Food oral processing: Some important underpinning principles of eating and sensory perception. Food Structure. 2014; 1(2):91-105.
5. Chen J. Food oral processing: Mechanisms and implications of food oral destruction. Trends in Food Science & Technology. 2015; 45(2):222-228.
6. de Lavergne MD, van de Velde F, Stieger M. Bolus matters: the influence of food oral breakdown on dynamic texture perception. Food & Function. 2017; 8(2):464-480.
7. Di Monaco R, Su C, Masi P, Cavella S. Temporal dominance of sensations: A review. Trends in Food Science & Technology. 2014; 38(2):104-112.
8. Diamante L, Umemoto M. Rheological properties of fruits and vegetables: a review. International Journal of Food Properties. 2015; 18(6):1191-1210.
9. Duconseille A, François O, Bruno P, Céline L, Marie-Agnès P, Martine H. Measuring the effects of *in vitro* mastication on bolus granulometry of shredded meat: A proposal for a new methodological procedure. Food Research International. 2019; 116:1266-1273.
10. Farooq M, Sazonov E. Automatic measurement of chew count and chewing rate during food intake. Electronics. 2016; 5(4):62.
11. Foster KD, Grigor JMV, Cheong JN, Yoo MJY, Bronlund JE, Morgenstern MP. The role of oral processing in dynamic sensory perception. Journal of Food Science. 2011; 76(2):R49-R61.
12. Foster KD, Woda A, Peyron MA. Effect of texture of plastic and elastic model foods on the parameters of mastication. Journal of Neurophysiology. 2006; 95(6):3469-3479.
13. Ghotra BS, Dyal SD, Narine SS. Lipid shortenings: a review. Food Research International. 2002; 35(10):1015-1048.
14. Hadde EK, Chen J. Shear and extensional rheological characterization of thickened fluid for dysphagia management. Journal of Food Engineering. 2019; 245:18-23.
15. Laguna L, Varela P, Salvador A, Fiszman S. A new sensory tool to analyse the oral trajectory of biscuits with different fat and fibre contents. Food Research International. 2013; 51(2):544-553.
16. Leon AM, Aguilera JM, Park DJ. Mechanical, rheological and structural properties of fiber-containing microgels based on whey protein and alginate. Carbohydrate Polymers. 2019; 207:571-579.
17. Marangoni F, Martini D, Scaglioni S, Sculati M, Donini LM, Leonardi F. others. Snacking in nutrition and health. International Journal of Food Sciences and Nutrition, 2019, 1-15.
18. Mellentin J, Heasman M. The functional foods revolution: healthy people, healthy profits. Routledge, 2014.
19. Nielsen A. Snack attack: what consumers are reaching for around the world. Nielson Nueva York, 2014.
20. Oladiran DA, Emmambux MN, de Kock HL. Extrusion cooking of cassava-soy flour with 200 g/kg wheat bran promotes slower oral processing during consumption of the instant porridge and higher derived satiety. LWT. 2018; 97:778-786.
21. Peyron MA, Mishellany A, Woda A. Particle size distribution of food boluses after mastication of six natural foods. Journal of Dental Research. 2004; 83(7):578-582.
22. Prakash S, Tan DDY, Chen J. Applications of tribology in studying food oral processing and texture perception. Food Research International. 2013; 54(2):1627-1635.
23. Prasad Reddy MN, Padma Ishwarya S, Anandharamakrishnan C. Nano encapsulation of roasted coffee bean oil in whey protein wall system through nanospray drying. Journal of Food Processing and Preservation. 2019; 43(3):e13893.
24. Priyanka S, Moses JA, Anandharamakrishnan C. Food Oral Processing and Tribology: Instrumental Approaches and Emerging Applications. submitted to Comprehensive Reviews in Food Science and Food Safety, 2019a.
25. Priyanka S, Moses JA, Anandharamakrishnan C. Oral processing behaviour of selected Indian rice varieties. Submitted to Journal of Texture Studies, 2019b.
26. Priyanka S, Moses JA, Anandharamakrishnan C. submitted to Physical, Sensory, *In vitro* Starch Digestibility and Glycemic Index of Granola Bars Prepared using Sucrose Alternatives. International Journal of Food Science & Technology, 2019c.

27. Repoux M, Labouré H, Courcoux P, Andriot I, Sémon É, Yven C, Guichard E. Combined effect of cheese characteristics and food oral processing on *in vivo* aroma release. Flavour and Fragrance Journal. 2012; 27(6):414-423.
28. Rizo A, Jimenez-Pérez I, Camacho-Garcia A, Fiszman S, Pérez-Soriano P, Tárrega A. Impact of texture TDS and flavour TDS tasks and of chocolate-chip biscuit characteristics on oral processing features. Food Quality and Preference. 2019; 76:109-117.
29. Roach M. Gulp: adventures on the alimentary canal. WW Norton & Company, 2013.
30. Rodrigues SA, Young AK, James BJ, Morgenstern MP. Structural changes within a biscuit bolus during mastication. Journal of Texture Studies. 2014; 45(2):89-96.
31. Rosenthal AJ, Pang A. Oral Processing of Crackers: Changes in the Secondary Textural Characteristics. J Nutr Food Lipid Sci. 2018; 1:1-5.
32. Tarrega A, Yven C, Semon E, Salles C. In-mouth aroma compound release during cheese consumption: Relationship with food bolus formation. International Dairy Journal. 2011; 21(5):358-364.
33. Theagarajan R, Malur Narayanaswamy L, Dutta S, Moses JA, Chinnaswamy A. Valorisation of grape pomace (cv. Muscat) for development of functional cookies. International Journal of Food Science & Technology, 2019.
34. Van Eck A, Hardeman N, Karatza N, Fogliano V, Scholten E, Stieger M. Oral processing behavior and dynamic sensory perception of composite foods: Toppings assist saliva in bolus formation. Food Quality and Preference, 2018.
35. Zbib IJ, Wooldridge BR, Ahmed ZU, Benlian S. Selection criteria of Lebanese consumers in the global snack food industry: country of origin perceptions. Journal of Consumer Marketing. 2010; 27(2):139-156.