TEXTURE ANALYSIS OF DIFFERENT INDIAN FRIED SNACKS USING ELECTROMYOGRAPHY

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Abstract
In this investigation electromyography (EMG) is being evaluated as a suitable technique to assess the texture of different Indian fried snacks. The study was conducted on ten subjects who were served with six samples, namely, ***paneer pakora****,* ***aloo pakora****, vegetable cutlet, cheese cutlet,* ***kachori*** *and* ***samosa****, in duplicate. The acquired EMG data was analyzed to obtain 31 variables which can comprehensively explain the mastication process. Due to higher inter-subject variance in absolute values of EMG variables, a two-way analysis of variance (ANOVA) was applied on their relative values. Significant ($p<0.05$) correlations between two recordings of a subject in a session was observed. Cluster analysis was performed to reduce 31 EMG variables to seven representative variables. Principal component analysis further classified these seven masticatory parameters into two independent meaningful components which could explain a cumulative variance of 83% in the acquired data. The results showed that out of all the EMG variables studied, inter-burst duration, cycle time per chew, early muscle activity and late amplitude can be used to explain the textural behavior of the Indian fried snacks used in the study. Further, first principal component scores significantly correlated with sensory hardness, fracturability, gumminess and adhesiveness, whereas second principal component scores correlated with sensory chewiness.*

Keywords: Mastication, electromyography, masseter muscles, principal component analysis, texture.

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1. INTRODUCTION

Electromyography is a non-invasive technique which can measure the bioelectric potential generated by masseter muscles in response to specific dynamic changes in texture during mastication (Sun et al., 2001). Texture is the rheological property of food products which can be defined by the sensory and functional expression of the structural, mechanical and surface characteristics of foods perceived through the senses of vision, hearing, touch and kinesthetic (Szczesniak, 2002). Texture perception determines the identity of food product and it is an important element in consumer sensory appreciation (Schiffman, 1977).

Mastication is known as the first and a significant step of the eating process (Iguchi et al., 2015). Chewing is the physiological act during which shear and compressive forces comminute food (Hutchings and Lillford, 1988) for easy swallowing and digestion (Nascimento et al., 2012). Mechanical nature and strength of the food are the principal factors which extremely influence the biting length and pattern throughout the chewing process (Chen, 2009). Gradual changes occur in the size, texture and moisture content of food during mastication process (Shiozawa et al., 2013) due to frequent application of force by teeth and the outcome of this activity is highly dependent upon the extent, speed and direction of applied force (Brown et al., 1998). These changing factors form the foundation of texture assessment by providing sensory responses (Brown et al., 1998). Texture differences between foods are more significant during initial stages of mastication and tend to decline during intra-oral transformation (Kohyama and Mioche, 2004). Human biting behaviour is also greatly affected by food geometry, with the increase in the thickness of sample the human's perception of food hardness increases from the

first bite (Chen, 2009).
Studies have revealed that the EMG responses vary significantly with food size, composition and rheology. Results obtained from EMG have indicated clear relationship between muscular activity and food characteristics. EMG enables better evaluation of sensory characteristics than mechanical measurements, and provides real-time information of the entire chewing process in order to characterize food texture. Therefore, this technique requires to be standardized for its applicability in formulation of food products. The present study has been conducted with the objective to record chewing pattern of different subjects for various Indian fried snacks with the help of EMG and to correlate it with sensory parameters so as to find the application of EMG in food texture evaluation.

2. MATERIALS AND METHODS

Subjects

The conduct of present study was approved by the Ethical Committee of Guru Nanak Dev University, Amritsar. In this investigation, ten young volunteers (females, aged 20 – 25 years) were selected as subjects to carry out EMG studies. Subjects were not having any abnormality in the number or position of teeth as well as no problem in mastication or swallowing (Shiozawa et al., 2013). Consent forms were obtained from all the subjects after the procedure was explained to them (Miyawaki et al., 2001).

Sample preparation

Different Indian fried snacks, namely, *paneer pakora*, *aloo pakora*, vegetable cutlet, cheese cutlet, *kachori* and *samosa* were procured from local market. The samples were cut into approximate blocks weighing 7 g.

Experimental session

The subjects were made to comfortably sit on the chair. The surface area of the skin on the masseter muscles was cleaned with a facial wipe. A small amount of conducting gel was applied on the skin before attaching electrodes (Gonzalez et al., 2004). Bipolar surface electrodes with an impedance of 50 Hz were secured on the masseter muscles. Ground electrode was placed on the left wrist as all the subjects were right-handed (Kohyama et al., 2007). The food samples were roughly cuboidal in shape and placed in a dish in front of the subjects. Subjects were then asked to eat six food samples, twice in random order, in their usual normal fashion of chewing (Shiozawa et al., 2013). The subjects rinsed their mouth with small amount of water after each chewing sequence so as to wash the food remnants from the mouth (Kohyama et al., 2002). The EMG signals were obtained by using electrodes, filtered (10 – 500 Hz) then amplified 2,000 times and recorded in PC using MP-150 system (Acknowledge ver. 4.4.2, Biopac Systems Inc.) at 1,000 Hz. Throughout the experimental session, the electrodes remained untouched (Karkazis and Kossioni, 1997). EMG signals were derived from both right and left sides of the masseter muscles. The EMG data were calculated from mean of both the muscles (Kohyama et al., 2008). Each session lasted for approximately 30-40 min. including explanation, preparation, application and removal of electrodes (Kohyama et al., 2002).

Sensory evaluation

Sensory assessment was conducted for six samples by ten subjects using hedonic scale. The subjects were asked to evaluate the food samples on the basis of sensory parameters viz. hardness, cohesiveness, fracturability, chewiness, gumminess and adhesiveness. The subjects gave evaluation accordingly on the sensory score card based on nine points, where one represented the least perceived sensation and nine represented the highest perceived sensation.

Data analysis

The EMG data was acquired using Acqknowlege (version 4.4) software. The acquired data were analysed by Minitab (Minitab Inc., USA) statistical software for conducting ANOVA, cluster analysis and principal component analysis.

3. RESULTS AND DISCUSSION

The EMG analysis was conducted for the mastication process and 31 variables were extracted from this analysis for: entire mastication process; per-chew mastication parameters; first-chew parameters; early stage mastication parameters; middle stage mastication parameters; and late stage mastication parameters.

Assessment of absolute and relative values of EMG variables

The acquired EMG variables were: no. of chews, mastication time, burst duration, total muscle activity, inter-burst duration, amplitude, burst duration per chew, muscle activity per chew, amplitude per chew, inter-burst duration per chew, cycle time per chew, first-chew burst duration, first-chew inter-burst duration, first-chew muscle activity, first-chew amplitude, first-chew cycle time, early burst duration, early muscle activity, early amplitude, early inter-burst duration, early cycle time, middle burst duration, middle muscle activity, middle amplitude, middle inter-burst duration, middle cycle time, late burst duration, late muscle activity, late amplitude, late inter-burst duration and late cycle time. The absolute values of these variables were subjected to a two-way ANOVA. The results indicated that the inter-subject variances were significantly ($p<0.05$) higher than the inter-sample variances (Tables 1 and 2). Similar findings have been reported earlier for EMG studies on cooked rice samples (Kohyama et al., 1998; Sodhi et al., 2010; Kohyama et al., 2016), different textured Indian food products (Rustagi, et al., 2018b) and Indian sweets (Sodhi et al., 2019). This necessitated the need to process the absolute values to relative values for further analysis. Relative values of EMG variables are frequently used in kinesiology to eliminate the subject variance (Kohyama et al., 2008). Accordingly, the relative values of EMG variables were calculated. The statistical analysis revealed that the relative values can effectively distinguish different Indian fried snacks (Tables 3 and 4).

Reproducibility of masseter muscle activities

Correlation analysis was conducted to study the reproducibility of the EMG variables of a subjects' duplicate recordings for a sample during: entire mastication parameters (burst duration, total muscle activity, inter-burst duration, no. of chews, amplitude and mastication time); per-chew mastication parameters (burst duration, inter-burst duration, cycle time, muscle activity and amplitude); first-chew parameters (burst duration, inter-burst duration, cycle time, muscle activity and amplitude); early stage mastication parameters (burst duration, inter-burst duration, cycle time, muscle activity and amplitude); middle stage mastication parameters (burst duration, inter-burst duration, cycle time, muscle activity and amplitude); and late stage mastication parameters (burst duration, inter-burst duration, cycle time, muscle activity and amplitude). Correlation coefficients of two different recordings in a session by a subject for mastication of fried snack samples were found to be statistically significant ($p<0.05$). High degree of similarity was also observed for a subject's chewing behavior from the dendrograms generated by cluster analysis. A representative dendrogram is shown in Fig. 1 depicting the reproducible chewing behavior. Similar results have been reported earlier for textural studies by EMG technique for Indian snacks (Pratiksha et al., 2018), different textured Indian foods (Rustagi et al., 2018a) and Indian sweets (Sodhi et al., 2019). Every individual has different chewing pattern for different textured food material, however inter-individual EMG data remains reproducible (Wilkinson et al., 2000). Karkazis and Kossioni (1997) also reported low variation in EMG activity for a subject within a session. Therefore, it can be concluded that human subjects have reproducible chewing behavior within a session. So EMG investigations of masseters muscles during chewing can be undertaken to study textural difference in foods.

Table 1. EMG data (absolute values) for various food samples showing subject and food factor variation for entire, per-chew and first-chew mastication periods.

PARAMETERS	*Paneer Pakora*	*Aloo Pakora*	Vegetable Cutlet	Cheese Cutlet	*Kachori*	*Samosa*	F value Subjects	F value Foods
Entire Mastication Parameters								
Mastication Time (s)	15.91	13.93	13.04	16.32	23.25	12.59	10.9	21.87
Number of Chews	22.9	20.7	19.1	24.1	31.55	19.3	7.91	15.69
Burst Duration (s)	7.16	6.20	5.57	7.25	10.60	5.61	13.17	16.59
Inter-burst Duration (s)	8.95	7.87	7.47	9.28	12.77	7.15	8.25	25.04
Muscle Activity (mV·s)	0.81	0.81	0.72	0.93	1.58	0.71	9.85	12.87
Amplitude (mV)	35.91	38.62	29.63	43.54	66.04	34.24	7.35	12.34
Per-chew Mastication Parameters								
Burst Duration (s)	0.30	0.29	0.28	0.29	0.34	0.28	56.28	10.84
Inter-burst Duration (s)	8.95	7.87	7.47	9.26	12.77	7.15	0.83	1.03
Muscle Activity (mV·s)	0.03	0.04	0.05	0.04	0.05	0.04	4.09	1.99
Amplitude (mV)	1.53	1.78	1.55	1.79	2.07	1.79	15.46	4.34
Cycle Time (s)	0.69	0.69	0.68	0.68	0.74	0.66	27.96	11.63
First-chew Mastication Parameters								
Burst Duration (s)	0.36	0.36	0.37	0.36	0.47	0.36	11.64	6.96
Inter-burst Duration (s)	0.41	0.43	0.38	0.39	0.36	0.42	1.44	0.89
Muscle Activity (mV·s)	0.02	0.04	0.02	0.04	0.06	0.04	1.75	4.34
Amplitude (mV)	103	1.25	1.07	1.31	1.96	1.43	2.89	6.29
Cycle Time (s)	0.76	0.79	0.73	0.75	0.81	0.78	7.04	0.97

Table 2. EMG data (absolute values) for various food samples showing subject and food factor variation for early stage, middle stage and late stage mastication periods.

PARAMETERS	*Paneer Pakora*	*Aloo Pakora*	Vegetable Cutlet	Cheese Cutlet	*Kachori*	*Samosa*	F value Subjects	F value Foods
Early Stage Mastication Parameters								
Burst Duration (s)	0.94	0.98	0.94	0.99	1.23	0.91	12.37	5.98
Inter-burst Duration (s)	1.15	1.08	1.07	1.05	1.18	1.03	7.54	2.8
Muscle Activity (mV·s)	0.10	0.13	0.09	0.13	0.19	0.14	5.81	6.16
Amplitude (mV)	4.32	4.96	3.98	5.29	6.42	5.26	5.73	5.55
Cycle Time (s)	2.12	2.07	2.01	2.08	2.39	2.13	2.97	2.03
Middle Stage Mastication Parameters								
Burst Duration (s)	0.89	0.85	0.82	0.83	1.00	0.85	21.17	6.61
Inter-burst Duration (s)	1.28	1.25	1.28	124	1.38	1.21	4.71	2.54
Muscle Activity (mV·s)	0.88	0.11	0.09	0.09	0.11	0.09	15.64	1.62
Amplitude (mV)	4.33	5.50	4.89	5.02	5.74	5.31	13.55	2.63
Cycle Time (s)	2.16	2.05	2.05	2.04	2.29	1.99	2.08	1.04
Late Stage Mastication Parameters								
Burst Duration (s)	0.84	0.80	0.81	0.8	0.84	0.79	22.29	1.90
Inter-burst Duration (s)	1.28	1.25	1.28	1.24	1.38	1.21	4.71	2.54
Muscle Activity (mV·s)	0.08	0.10	0.09	0.09	0.11	0.09	15.64	1.62
Amplitude (mV)	4.33	5.50	4.89	5.02	5.74	5.31	13.56	2.63
Cycle Time (s)	2.16	2.05	2.05	2.04	2.29	1.99	2.08	1.04

Table 3. EMG data (relative values) for various food samples showing food factor variation for entire, per-chew and first-chew mastication periods.

PARAMETERS	*Paneer pakora*	*Aloo Pakora*	Vegetable Cutlet	Cheese Cutlet	*Kachori*	*Samosa*	F value	p value
Entire Mastication Parameters								
Mastication Time (s)	0.99	0.87	0.81	1.02	1.45	0.80	22.57	0.00
Number of Chews	0.99	0.89	0.83	1.05	1.39	0.85	15.74	0.00
Burst Duration (s)	0.99	0.86	0.77	1.01	1.57	0.80	17.69	0.00
Inter-burst Duration (s)	0.99	0.88	0.83	1.04	1.45	0.81	24.78	0.00
Muscle Activity (mV·s)	0.83	0.84	0.72	0.99	1.85	0.76	11.58	0.00
Amplitude (mV)	0.85	0.91	0.72	1.04	1.63	0.83	9.81	0.00
Per-chew Mastication Parameters								
Burst Duration (s)	1.01	0.98	0.95	0.98	1.13	0.96	9.69	0.00
Inter-burst Duration (s)	0.99	0.98	0.99	1.06	1.026	0.94	1.03	0.04
Muscle Activity (mV·s)	0.85	0.93	1.03	0.95	1.33	0.91	2.1	0.08
Amplitude (mV)	0.88	1.02	0.88	1.01	1.19	1.01	3.32	0.01
Cycle Time (s)	1.01	0.99	0.98	0.98	1.08	0.96	11.85	0.00
First-chew Mastication Parameters								
Burst Duration (s)	0.96	0.95	0.88	0.96	1.26	0.98	6.04	0.00
Inter-burst Duration (s)	1.02	1.08	0.97	0.98	0.91	1.05	0.89	0.49
Muscle Activity (mV·s)	0.74	1.02	0.69	0.89	1.74	0.92	6.69	0.00
Amplitude (mV)	0.77	0.95	0.81	0.93	1.59	1.06	6.45	0.00
Cycle Time (s)	0.99	1.02	0.94	0.98	1.04	1.01	0.99	0.43

Table 4. EMG data (relative values) for various food samples showing food factor variation for early stage, middle stage and late mastication periods.

PARAMETERS	*Paneer pakora*	*Aloo Pakora*	Vegetable Cutlet	Cheese cutlet	*Kachori*	*Samosa*	F value	p value
Early Stage Mastication Parameters								
Burst Duration(s)	0.94	0.97	0.93	0.98	1.28	0.90	4.91	0.00
Inter-burst Duration (s)	1.05	0.99	0.98	0.95	1.08	0.95	3.03	0.01
Muscle Activity (mV·s)	0.81	0.93	0.74	0.94	1.56	1.02	7.05	0.00
Amplitude (mV)	0.85	0.99	0.80	1.03	1.29	1.03	6.26	0.00
Cycle Time (s)	0.99	0.97	0.94	0.98	1.12	0.99	2.24	0.06
Middle Stage Mastication Parameters								
Burst Duration (s)	1.03	0.97	0.93	0.96	1.15	0.97	6.73	0.00
Inter-burst Duration (s)	0.98	0.98	1.07	0.97	1.09	0.93	4.89	0.00
Muscle Activity (mV·s)	0.89	0.97	0.86	0.97	1.37	0.94	6.47	0.00
Amplitude (mV)	0.89	0.95	0.94	1.06	1.17	1.04	0.09	0.13
Cycle Time (s)	0.99	0.97	1.00	0.97	1.11	0.95	14.19	0.00
Late Stage Mastication Parameters								
Burst Duration (s)	1.06	0.98	0.99	0.97	1.03	0.96	2.12	0.08
Inter-burst Duration (s)	1.01	0.98	1.00	0.98	1.09	0.95	2.54	0.04
Muscle Activity (mV·s)	0.91	1.07	0.94	0.96	1.13	0.99	1.50	0.20
Amplitude (mV)	0.87	1.06	0.95	0.98	1.12	1.03	1.78	0.13
Cycle Time (s)	1.03	0.98	0.98	0.98	1.08	0.95	0.90	0.48

Principal component analysis

Principal components analysis is a valuable technique for selecting smaller number of variables from a group of large variables. In the current study, 31 masticatory parameters were reduced to seven representative parameters viz. inter-burst duration, middle inter-burst duration, cycle time per chew, mastication time, early muscle activity, late amplitude, first inter-burst duration, by classifying them into seven clusters for further processing by principal component analysis (Fig. 2).

The principal component analysis of these seven parameters resulted in two independent meaningful components. The cumulative proportion of variance for first principal component (PC1) was 66.1% and for second principal component (PC2) was 83.0% (Table 5).

Table 5. Principal component factor loading of the masticatory parameters.

Parameter	PC1	PC2
Inter-burst duration	**0.455**	-0.058
Middle inter-burst duration	0.341	-0.114
Cycle time per chew	**0.440**	-0.084
Mastication time	0.335	-0.397
Early muscle activity	**0.404**	0.389
Late amplitude	0.250	**0.761**
First inter-burst duration	-0.380	0.294
Cumulative proportion (%)	**66.1**	**83.0**

The PC1 was having relatively higher values in order of inter-burst duration, cycle time per chew and early muscle activity, while late amplitude showed higher value for PC2. All the food samples were having different scores indicating differences in their texture attributes during mastication by human subjects (Fig. 4). The fried snack samples having similarities in textural behavior were placed in the same quadrant viz. *samosa* and *aloo pakora;* and vegetable cutlet, cheese cutlet and *paneer pakora*. However, *kachori* was placed in a separate quadrant indicating a totally different textured fried snack owing to its harder crust.

The principal component scores of these six Indian fried snacks were correlated with sensory parameters (Table 6). The scores of PC1, which mainly comprised of inter-burst duration, cycle time per chew and early muscle activity, were correlated significantly with sensory hardness, fracturability, gumminess and adhesiveness. Whereas scores of PC2, which mainly comprised of late amplitude, correlated with sensory chewiness. Kohyama et al. (2008) reported that adhesiveness mostly affected the mastication parameters from the middle to late stages in their EMG studies. Also, Anderson et al. (2002), Peyron et al. (1997) and Kohyama et al. (2014) reported that hardness of food samples affected the chewing performance of human subjects.

Table 6. Correlation coefficients between the scores of principal components and sensory parameters.

Parameter	PC1	PC2
Hardness	**0.824****	0.310
Cohesiveness	-0.450	-0.603
Fracturability	**0.664***	0.545
Chewiness	0.302	**-0.781****
Gumminess	**0.628***	-0.426
Adhesiveness	**0.620***	0.008

**p≤0.1; *p≤0.2

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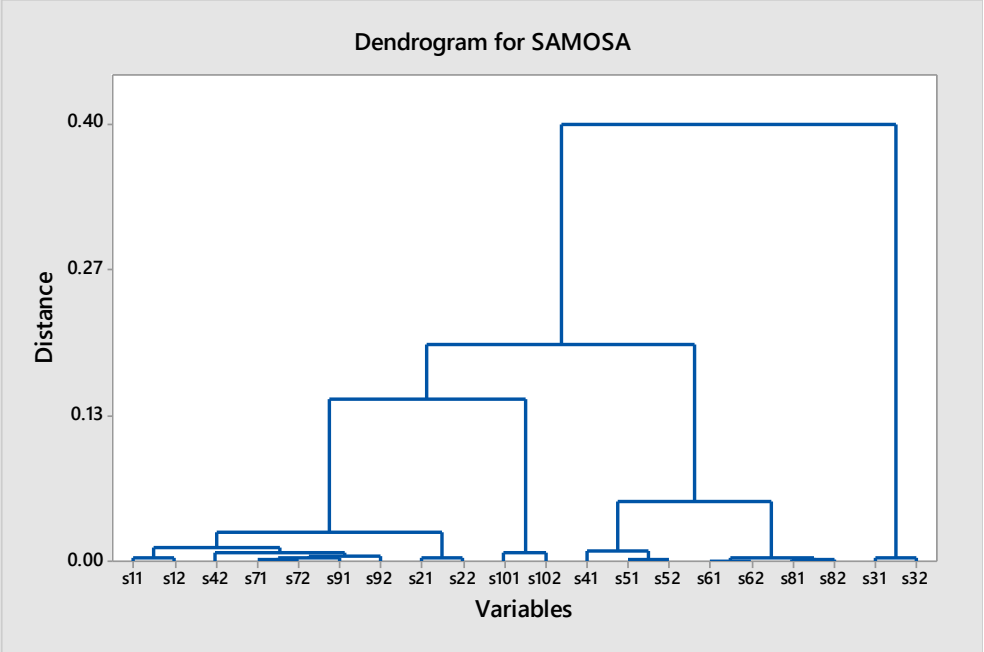

Fig. 1: Representative dendrogram showing reproducibility of masseter muscle activity for *samosa*.

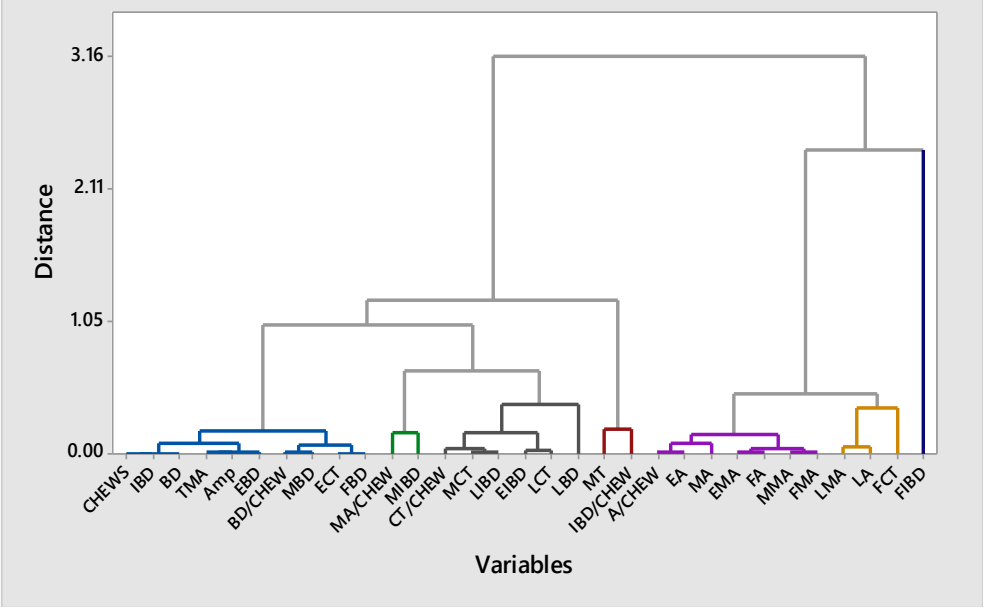

Fig. 2: Dendrogram showing whole masticatory parameters grouped into seven clusters.

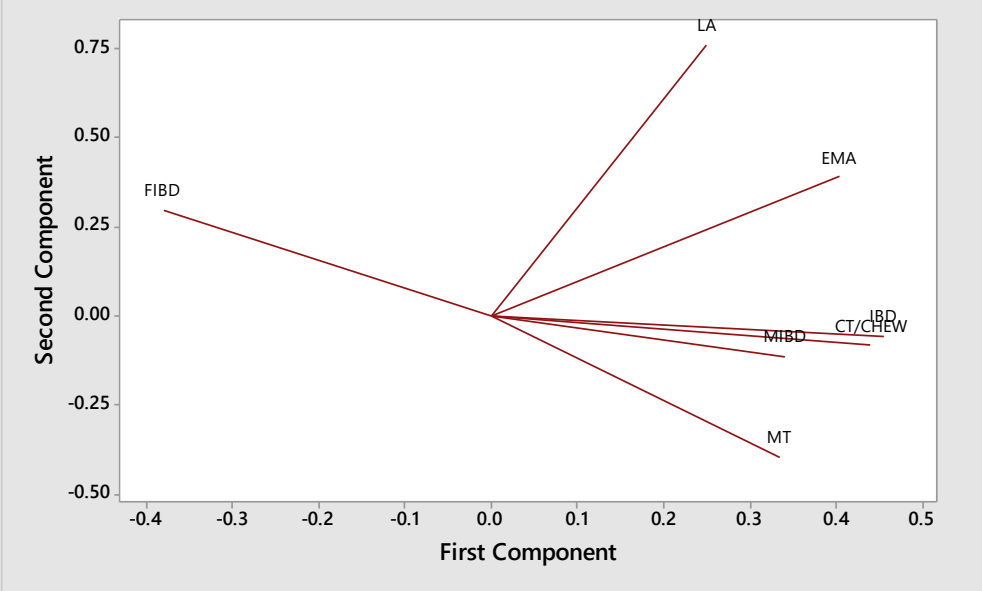

Fig. 3: Principal component loading plot for EMG mastication parameters.
(FIBD: First chew inter-burst duration; LA: Late amplitude; EMA: Early muscle activity; IBD: Inter-burst duration; CT/CHEW: Cycle time per chew; MIBD: Middle inter-burst duration; MT: Mastication time)

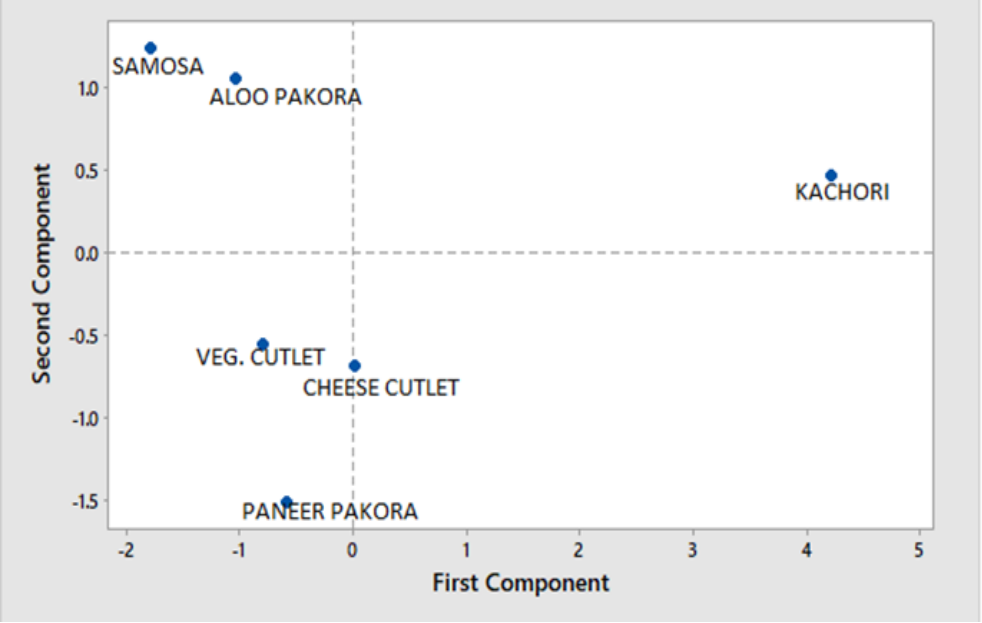

Fig. 4: Principal component score plot for different foods.

The principal component scores of these six Indian fried snacks were correlated with sensory parameters (Table 6). The scores of PC1, which mainly comprised of inter-burst duration, cycle time per chew and early muscle activity, were correlated significantly with sensory hardness, fracturability, gumminess and adhesiveness. Whereas scores of PC2, which mainly comprised of late amplitude, correlated with sensory chewiness. Kohyama et al. (2008) reported that adhesiveness mostly affected the mastication parameters from the middle to late stages in their EMG studies. Also, Anderson et al. (2002), Peyron et al.

(1997) and Kohyama et al. (2014) reported that hardness of food samples affected the chewing performance of human subjects.

4. CONCLUSION

Texture analysis of different Indian fried snacks was conducted using electromyographic technique. In this study, absolute EMG variables were processed to relative values to eliminate subject variance. It is further inferred from the study that human chewing behavior is highly reproducible and EMG variables can be significantly related to human subjects' food texture perceptions. The fried snacks having similar texture were clustered together. Thirty-one EMG parameters were reduced to seven representative parameters out of which two independent meaningful components were deduced for further analysis. The first principal component, mainly composed of inter-burst duration, cycle time per chew and early muscle activity, was significantly correlated with sensory hardness, fracturability, gumminess and adhesiveness, whereas the second principal component, mainly composed of late amplitude, significantly correlated with sensory chewiness. EMG technique allowed us to study textural changes inside mouth by providing the *in-vivo* information and can be related to sensory texture analysis for comprehensive understanding of dynamic textural changes during mastication.

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