

Physiochemical and nutritional characterization of coconut (*Cocos nucifera* L.) haustorium based extrudates

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ABSTRACT

Rice and maize are commonly used for the production of extrudates and incorporation of nutritionally rich materials is prime important to make extrudates nutritionally superior. Coconut haustorium, a nutrient rich spongy tissue formed during coconut germination, was added to rice and maize (1:1) flour at levels of 0%, 10%, 20% and 30% (w/w) by replacing the maize and extruded in twin-screw extruder. Effect of addition of haustorium on the physico-chemical parameters like bulk density, expansion ratio, water absorption index, water solubility index, hardness, breaking force, breaking strength, compressive strength, color parameters like L*, hue, and chroma value, sensory characteristics and biochemical parameters like proximates, minerals, phenolics, flavonoids and antioxidant potential in the extrudates were studied. Results indicated that the addition of haustorium had a significant effect on parameters studied. Incorporation of haustorium resulted in less expanded, lengthy, dark colored, hardened, protein, minerals, phenolics and flavonoids rich extrudates with high anti-oxidant activity. A combination of 50% rice, 30% maize and 20% haustorium was found suitable for healthy and nutritious extrudates preparation based on the biochemical constituents and overall sensory acceptability.

1. Introduction

Snack foods, an integral part of eating habit of the majority of the world's population, are prepared from natural ingredients or components with specified nutritional and functional properties (Ibanoglu, Ainsworth, Özer, & Plunkett, 2006). Various processing methods are employed to produce snack food. Among them, extrusion cooking has become popular for multiple reasons like its versatility, high productivity, energy efficiency, shorter cooking time, better product quality and low operating cost (Köksel, Ryu, Başman, Demiralp, & Ng, 2004). It is used worldwide for the preparation of expanded snack foods, baby foods, ready-to-eat foods, etc. In the extrusion process, the raw material is made to flour and moistened, then subjected to high temperature treatment for short time cooking, wherein the desired level of temperature is achieved through shearing and friction forces created in the extruder (Ganjyal, Hanna, & Jones, 2003). Since the material is exposed to high temperature and pressure due to shearing force for short period, its nutrients are preserved and the desirables changes like starch gelatinization, protein denaturation, food enzymes inactivation

and reduction of microbial counts occurs (Basediya, Pandey, Shrivastava, Khan, & Nema, 2013).

Cereals, particularly rice (*Oryza sativa* L.) and maize (*Zea mays* L.), are commonly used as raw materials for the production of extrudates due to their functional properties, low cost, and ready availability. Recently, incorporation of pulses in the cereal based extrudates has drawn attention among the food technologists due to their high protein content (Deshpande & Poshadri, 2011). Food fortification with nutrients is a novel approach for alleviation for various diseases and nutrient-dependent disorders. Further, consumption of foods with essential nutrients has gained greater attention among the consumers. Since, snack foods are emerging into modern day alternatives for elaborate full-fledged meals, improvement of the quality of these products with the incorporation of other nutritionally rich ingredients is an effective approach to increase the nutritional quality of the products. Coconut haustorium (*Cocos nucifera* L.), a spongy tissue forms during the germination of coconut, is a rich source of nutrients like dietary fibre, iron, phenolics, and antioxidants (Manivannan et al., 2016), and presently it is highly underutilized. Hence, this study was conducted to develop

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new rice and maize based extrudates with the incorporation of varying proportion of coconut haustorium and to evaluate physical, textural and nutritional characteristics of extrudates. Thus, this study will provide new insights to utilize coconut haustorium in better way to exploit their nutrient richness.

2. Materials and methods

2.1. Preparation of raw materials and feed for extrusion

Coconut haustorium was prepared from germinated coconut by following the method described by Manivannan et al. (2016). Rice and maize flours were purchased from the local market and used for the study. Rice flours used was made from broken rice which is low cost and under-utilized by-product of rice milling plants. Rice, maize and coconut haustorium flours were sieved through British Standard (BS) Sieve of 14 mesh size (1 mm). Different combination of flours were mixed as mentioned: 100% rice, 50% rice + 50% maize, 50% rice + 40% maize + 10% coconut haustorium, 50% rice + 30% maize + 20% coconut haustorium and 50% rice + 20% maize + 30% coconut haustorium. The different formulations were prepared for extrusion process according to the method described by Morsy, Rayan, and Youssef (2015).

2.2. Extrusion

Extrusion was performed on co-rotating twin-screw extruder (10.0 HP motor, 400 V, 50 cycles, L-TSE model, Basic Technologies Private Ltd., Kolkata, India) with die opening of 3.0 mm. Preconditioned feed mixture was metered into the extruder by a twin-screw volumetric feeder equipped with it. The extruder has three barrel zones with a total length of 350 mm and length to diameter ratio of 5:1. Preliminary extrusion trials were conducted to identify the level of different operating parameters. The extruder was operated at a feeder speed 35 rpm, feed rate 10.5 kg h⁻¹ and die section (third zone) temperature of 120 ± 2 °C after ascertaining the stabilized recovery of extrudates of all treatments. The temperature of the first and second zone was maintained at 40 ± 2 and 80 ± 2 °C, respectively, for all the experiments. The zones were heated and cooled at two sections by a separate water circulation system. Steady-state conditions were assumed to have been reached when there were no visible drifts in percentage torque, pressure and product temperature at the die for at least 5 min. Extrudate rods were cut through a constant cutter speed (15 rpm.), dried at 40 ± 2 °C for 30 min in air circulatory tray drier and stored in polyethylene bags (thickness-75 µ/300 gauge) at ambient conditions (30–35 °C) for further analysis.

2.3. Measurement of physical and functional properties of extruded products

Specific length (SL) was measured as the ratio of Length of specimen (mm) to the weight of specimen (g) of and it is expressed in mm/g. Expansion ratio was expressed as the ratio of the diameter of extrudates to the diameter of the die, at the dry stage of the extrudates. Bulk density is the mass per unit bulk volume of the material where the volume includes the volume of voids and calculated by the formula, bulk density (g/mL) = Weight of extrudates (g)/Volume of extrudates (mL) (Patil, Berrios, De, Tang, & Swanson). Water absorption index (WAI) and water solubility index (WSI) were determined as described by Silva et al. (2009) and oil absorption index (OAI) was determined according to the method of Liadakis, Floridis, Tzia, and Oreopoulou (1993).

2.4. Measurement of color and textural parameters in extrudates

The color values of the ground extrudate samples were measured

with a Konica Minolta Spectrophotometer CM-2500c (Japan) using CIELAB scale at 10° observer and D65 illuminant. The measurements were taken for two color co-ordinates, a^* and b^* , as well as psychometric index of lightness, (L^*).

Chroma was calculated using equation $C^* = (a^{*2} + b^{*2})^{1/2}$ and Hue angle (h^*) was calculated using the equation $h^* = \tan^{-1}(b^*/a^*)$. The textural characteristics of coconut haustorium based extrudates such as hardness, breaking force, breaking strength, and compressive strength were measured using a texture analyzer (Model TA-XT Plus, Stable Microsystems, UK). The software used for analysis of the curve was Texture Expert™. Hardness and compressive strength of the extrudates were measured using cylindrical probe P/2 of texture analyzer. Breaking (or) cutting force and strength of extrudates was measured using the HDP/BS blade. All the experiments were replicated thrice by taking measurement on 5 samples from each set.

2.5. Measurement of proximate composition, phenolics and antioxidant potential of the extrudates

The proximate composition of coconut haustorium based extrudates viz. moisture (AOAC 934.01), ash (AOAC 938.08), protein (AOAC 2001.11) and fat (AOAC 920.58) was determined using the official methods (AOAC, 2005). Eighty percent ethanol extract of extrudates was used to determine the total sugar, reducing sugar, phenolics and antioxidant potential using appropriate methods. The residue after extraction was used for starch estimation. Total soluble sugar and reducing content in the extract was determined using phenol-sulphuric acid method (DuBois, Gilles, Hamilton, Rebers, & Smith, 1956) and Nelson-Somogyi's method (Somogyi, 1952), respectively. Starch content was estimated as per AOAC 996.11. Determination of total phenolic content in the extract was done using Folin-Ciocalteu (FC) assay as described by Singleton, Orthofer, and Lamuela-Raventos (1999) and expressed as mg gallic acid equivalent (GAE) per 100 g extrudates. The total flavonoid content (TFC) was determined according to Zhishen, Tang, and Wu (1999) and expressed as mg of quercetin equivalent (QE) per 100 g of the extrudates. Antioxidant potential of extrudates in terms of reducing power was measured by two methods viz. FRAP, and CUPRAC. The FRAP (Ferric Reducing Antioxidant Power) assay was done according to Benzie and Strain (1996) and Cupric ion reducing antioxidant capacity (CUPRAC) of the extract was determined according to the method of Apak, Guclu, Ozyurek, and Karademir (2004). In both the methods, Trolox was used as a positive control and results were expressed in mg TE (Trolox equivalent)/100 g dry weight.

2.6. Mineral analysis

Mineral content was determined in accordance with the official analytical methods (AOAC, 2005) using a GBC Avanta PM atomic absorption spectrometer (AAS) (GBC Scientific Equipments, Australia) equipped with a D₂ lamp background correction system using an air-acetylene flame. Phosphorus present in the haustorium based extrudates was determined by molybdovanadophosphoric acid method described by Kitson and Mellon (1944) using the spectrophotometer.

2.7. Sensory evaluation

Sensory methods are fast, simple and provide immediate quality information. The sensory analysis involves sight, tactile and olfaction senses. Each attribute is translated to a numeric scale using a 9 point hedonic score system (Bremner, 2000). The sensory evaluation of the resultant extrudates without seasoning materials was carried out with coded samples in laboratory where separate area has been earmarked with suitable lighting using white LED lights under controlled temperature (20–22 °C) and relative humidity (40 ± 5%). Seven properties namely, taste, crispness, odor, chewiness, color, surface characteristics and pore distribution that constitute overall acceptability



Fig. 1. Coconut haustorium based extruded products. A - 100% Rice; B - 50% rice + 50% maize; C - 50% rice + 40% maize + 10% coconut haustorium; D - 50% rice + 30% maize + 20% coconut haustorium; E - 50% rice + 20% maize + 30% coconut haustorium.

were judged by semi-trained panelist consisting of 6 members (3 males and 3 females, age 23 to 55).

2.8. Statistical analysis

All the experiments including determination of various parameters were conducted in triplicates. All data were expressed as means \pm Standard Deviation (SD). The influence of adding the coconut haustorium powder to rice and maize based extrudates on the studied properties of extrudates was analyzed using analysis of variance (ANOVA) and Duncan's multiple range tests to detect significant differences between samples. Significant differences were defined at $P < 0.05$. Linear correlation was also performed to study the relationship between the parameters studied. All analysis was performed using SAS program version 9.3. (SAS, 2012).

3. Results and discussion

Rice and maize based extrudates were prepared by incorporating different proportion of the coconut haustorium at the rate of 10–30% (w/w) by replacing maize and the resultant products are represented in Fig. 1.

3.1. Physical properties of coconut haustorium based extrudates

Physical properties viz. specific length, bulk density, and expansion ratio of the coconut haustorium incorporated rice and maize based extrudates were given in Table 1.

3.1.1. Specific length

The specific length of extrudates correlates with length and weight measured in terms of axial expansion. It was observed that the incorporation of haustorium to rice and maize blend significantly increased the specific length from 68.6 to 102 mm/g with an increase in haustorium content from 10 to 30%. The increase in SL may be attributed to the high denaturation of haustorium proteins and poor gelatinization of starch (Basediya et al., 2013).

3.1.2. Expansion ratio (ER)

Expansion ratio, being an important characteristic of extrudates, measures the degree of puffing undergone by the product as it exits the extruder. It is highly influenced by the extrusion processing variables, physical and biochemical characteristics of raw materials used. The ER

was found to be high in extrudates made using 50% rice + 50% maize (3.658 ± 0.015) followed by 100% rice (3.311 ± 0.126). The ER was significantly affected due to the incorporation of haustorium, as the ratio decreased from 3.044 to 1.571 with an increase in haustorium incorporation from 10% to 30%, respectively. Production of numerous tiny steam bubbles due to the rapid release of pressure after exiting the die is the prime reason for the formation of porous, expanded sponge-like structure (Suknark, Phillips, & Chinnan, 1997). Starch content, size, number and distribution of air cells within the extruded material determine the degree of expansion. Decrease in starch content and increase in protein and oil content in the blend due to the addition of haustorium significantly affected the expansion ratio of the extrudates. The reduction in expansion ratio could be attributed to the interaction of various compounds in the haustorium with starch and the reduction in elasticity of the blend due to protein and fibre (Onwulata, Konstance, Smith, & Holsinger, 2001). Higher water holding capacity of fibres compared to starch reduces the water loss at the die and thus reduces its ability for expansion and also reduces the availability of water for gelatinization of starch. Moreover, increasing sugar levels due to the addition of haustorium compete with starch granules for the limited water available in the system for starch conversion and therefore lower the water activity. This results in less steam being available to feed expanding cells during the expansion process and a decreased rate of starch conversion and therefore reduced elasticity of the melt. Consequently, the extrudates have lower moisture contents, expand less and collapse more readily after leaving the die and so have higher bulk densities (Ojokoh et al., 2015).

3.1.3. Bulk density

The bulk density of the resultant extrudates significantly increased with incorporation of haustorium, especially at higher levels (20–30%). Bulk density can be inversely related to expansion ratio, because decrease in expansion leads to increase in bulk density and vice versa. From the earlier studies, it was confirmed that the incorporation of materials containing high fibre, protein and sugar to the starch based extruded products, increase in density is expected. Regardless of the nature of the source, fibre exerts a concentration-dependent effect on extrudate expansion. Previous studies reported that incorporation of 20–30% rice bran, wheat and oat bran significantly reduced the radial and axial expansion of rice flour and corn-based extrudates, respectively (Grenus, Hsieh, & Huff, 1993). The presence of simple sugars and fibers absorb water and thus the availability of water for expansion is reduced, which in turn reduces the size and number and distribution of

Table 1
Physical and functional properties of coconut haustorium based extrudates.

Extrudates combination	SL (mm/g)	ER	BD (g/mL)	WAI (g/g)	WSI (%)	OAI (mL/g)
100% R	83.5 ^b \pm 3.4	3.311 ^b \pm 0.126	0.131 ^d \pm 0.006	8.67 ^a \pm 0.15	18.7 ^c \pm 0.23	1.257 ^a \pm 0.09
50% R + 50% M	72.7 ^c \pm 2.1	3.658 ^a \pm 0.015	0.133 ^d \pm 0.003	7.17 ^b \pm 0.69	18.4 ^c \pm 1.01	1.340 ^a \pm 0.04
50% R + 40% M + 10% CH	68.6 ^c \pm 3.2	3.044 ^c \pm 0.051	0.203 ^c \pm 0.005	6.87 ^b \pm 0.17	19.3 ^{bc} \pm 0.40	0.851 ^b \pm 0.02
50% R + 30% M + 20% CH	81.8 ^b \pm 0.7	1.824 ^d \pm 0.085	0.342 ^b \pm 0.007	5.24 ^c \pm 0.06	21.1 ^{ab} \pm 0.63	0.684 ^c \pm 0.01
50% R + 20% M + 30% CH	102.0 ^a \pm 3.0	1.571 ^e \pm 0.034	0.369 ^a \pm 0.005	4.83 ^c \pm 0.09	22.4 ^a \pm 0.79	0.637 ^c \pm 0.04

Results are represented as mean \pm standard deviation of three independent experiments; SL-specific length; ER-expansion ratio; BD-bulk density; WAI- water absorption index; WSI-water solubility index; OAI- oil absorption index; Different letters in each column after the mean value are significantly different at 5% level according to Duncan's Multiple Range Test (DMRT).

air cells inside the extrudates (Onwulata et al., 2001). It is also stated that the presence of excess fibre may rupture the cell walls and prevents the expansion of air bubbles to their maximum level, which is reflected in bulk density (Kaletunc & Breslauer, 1993). The results obtained in this study concur with the observation made by previous reports. Significant negative correlation was found at 5% level of significance between the expansion index and bulk density ($r = -0.990$) [linear correlation data are given in supplementary material 1].

3.2. Functional properties of coconut haustorium based extrudates

The suitability of extrudates for application depends on their functional properties such as water absorption, water solubility, and oil absorption indices. Functional properties of the extrudates are, generally, related to the molecular modifications that occur during extrusion cooking process. Results obtained for various functional properties are given in Table 1.

3.2.1. Water absorption index

The amount of water absorbed by the starch and other hydrophilic compounds present in the extrudates is measured as water absorption index. Gelatinized starch has the capacity to absorb the maximum amount of water compared to other constituents in the extrudates, WAI can be used as an index of gelatinization. Incorporation of coconut haustorium in the rice and maize blend significantly ($P < 0.05$) affected the WAI. The WAI was found high in 100% rice based extrudates (8.67 g/g) and less in 30% haustorium incorporated extrudates (4.83 g/g). The reduction in the WAI due to the incorporation of haustorium could be attributed to the reduction of starch content in the final products as the haustorium contains only 20% of starch, whereas rice and maize contain about 70% and 60% starch, respectively.

3.2.2. Water solubility index

Degradation of complex molecular compounds in the extruded products can be indicated by WSI. The degree of starch dextrinization during the extrusion process can also be measured by WSI. Incorporation of coconut haustorium significantly increased the water solubility index from 18.7% (100% rice) to 22.4% (30% haustorium incorporated). Since the coconut haustorium contained a large amount of soluble sugars, the incorporation of haustorium led to significant increase in WSI.

3.2.3. Oil absorption index

Like WAI and WSI, Oil absorption index (OAI) is a functional characteristic feature of extrudates and it measures the oil holding capacity of the extrudates. The increase in haustorium content in the extrudates significantly decreased the OAI. The extrudates of 50% rice and 50% maize showed higher OAI (1.34 mL/g) whereas the extrudates incorporated with 30% haustorium exhibited less OAI (0.637 mL/g). The absorption of oil by the extrudates could be attributed either to physical entrapment of oil in the extrudates or due to the absorption of oil by the nonpolar side chains of the chemical components (Chauhan & Bains, 1988). Present study suggests that the oil entrapment mechanism could play major role since the OAI values were found to be lower in those samples which contain more of hydrophilic compounds which retard the absorption of the oil.

3.3. Textural properties of coconut haustorium based extrudates

Four textural characteristics viz. hardness, compressive strength, breaking force and breaking strength were studied using texture analyzer and results are given in Table 2. The hardness of expanded extrudates is the peak force required for a probe to compress the extrudates. It is a perception of the human being and is associated with expansion and cell structure of the products (Meng, Threinen, Hansen, & Driedger, 2010). Higher value of peak force indicates the

higher hardness of the sample. Hardness values range from 45.2 to 160.5 N. Low hardness is a favoured property of extrudates, and incorporation of coconut haustorium at the rate of 10–20% significantly reduced the hardness from 120 N (50% rice + 50% maize) to 45.2 and 107.9 N, respectively, while the hardness increased to 160.5 N with 30% incorporation of haustorium. Hardness showed significantly positive correlation with compressive strength ($r = 0.966$, at $P < 0.05$).

The compressive strength of the expanded extrudates varied from 47.3 Nmm to 261 Nmm. Like hardness, incorporation of coconut haustorium significantly increased the compressive strength from 47.3 to 261 Nmm for 10–30% incorporation. Breaking force of the resultant extrudates varied from 18.0 to 44.5 N. Eventhough, the average value of breaking force of the extrudates showed increasing trend with the incorporation of coconut haustorium from 10 to 30%, no significant differences were observed between extrudates. It can be due to the huge variation in the standard deviation of the replicated values. Breaking strength of the resultant extrudates ranged from 38.4 to 3.9Nmm. Incorporation of coconut haustorium significantly reduced the breaking strength and the rate of reduction was 2, 7.2 and 9.8 fold for 10–30% haustorium incorporation.

Up to 10% level of haustorium incorporation, the fat, protein and sugar present in haustorium might have facilitated the starch matrix (i.e. the viscoelastic properties of molten extrudate) for the weakening of cell wall resulted in increased pore structure due to air cell and reduction of textural attributes such as hardness and compressive strength (Alam, Kaur, Khaira, & Gupta, 2016; Nascimento, Carvalho, Takeiti, Freitas, & Ascheri, 2012). The high content of protein and lipids upon addition of haustorium at more than 10% might have affected characteristics of the starch matrix so that it no longer holds water vapour, resulting in higher hardness and compressive strength of the extrudate (Mesquita, Leonel, & Mischan, 2013).

3.4. Color attributes of coconut haustorium based extrudates

Color is one of the important characteristics of quality index of food product, which affects the consumer perception towards the product. It holds a pre-eminent position on food acceptance, and it can be used as a predictor of non-sensory attributes like moisture content, over-processing and the pigment content (Moyano, Melendez-Martinez, Alba, & Heredia, 2008). The color values obtained for extrudates prepared by incorporation of different proportions of coconut haustorium was given in Table 2. The color parameter L^* (luminosity) varied from 57.1 to 70.1 in a 1 to 100 scale, the value decreased with the addition of coconut haustorium. The reduction in the lightness may be attributed to the presence of phenolics, flavonoids and other pigments in the coconut haustorium. Previous study demonstrated that the phenolics and other pigments present in the raw material undergo non-enzymatic browning promoted by the sugars in the added materials and degradation of the pigments (Selani, Canniatti Brazaca, Santos Dias, & Ratnayake, 2014).

Chroma indicates the saturation and is directly proportional to the intensity of the color and incorporation of coconut haustorium significantly increased the chroma values compared to control. The values ranged between 7.56 and 34.6. Chroma value had significant negative correlation with hue angle. The increase in Chroma value with the incorporation of haustorium could be due to the presence of phenolics and flavonoids in the haustorium. Earlier reports suggest that the heating also causes increase in color due to the caramelization of sugar present in the raw materials (Hagenimana et al., 1996). Hue angle also used as a color quality parameter in processed foods and the value obtained in the study ranged between 79.8 and 94.0.

3.5. Biochemical and mineral composition of extrudates

The biochemical composition of coconut haustorium based extrudates is given in Table 3. Significant difference was observed for the biochemical parameters studied. Moisture content significantly reduced

Table 2
Textural properties and color attributes of coconut haustorium based extrudates.

Parameters	100% R	50% R + 50% M	50% R + 40% M + 10% CH	50% R + 30% M + 20% CH	50% R + 20% M + 30% CH
Textural properties					
Hardness (N)	122.9 ^b ± 20	120.1 ^b ± 23	45.2 ^c ± 10	107.9 ^b ± 25	160.5 ^a ± 18
Compressive strength (Nmm)	149.8 ^{bc} ± 11	181.4 ^b ± 19	47.3 ^d ± 26	129.3 ^c ± 17	261.2 ^a ± 33
Breaking Force (N)	20.9 ^b ± 3.6	44.5 ^a ± 3.7	18.0 ^b ± 3.3	22.4 ^b ± 8.8	16.5 ^b ± 7.6
Breaking strength (Nmm)	25.5 ^b ± 6.2	38.4 ^a ± 12	19.2 ^b ± 2.3	5.3 ^c ± 1.6	3.9 ^c ± 2.3
Color attributes					
L*	70.1 ^a ± 5.7	64.6 ^a ± 2.3	57.1 ^b ± 3.4	64.4 ^a ± 0.4	66.1 ^a ± 3.5
C	7.56 ^d ± 1.2	26.9 ^c ± 0.8	27.2 ^c ± 1.8	31.4 ^b ± 0.9	34.6 ^b ± 0.5
H	94.0 ^a ± 1.7	86.2 ^b ± 0.7	84.8 ^b ± 0.2	81.5 ^c ± 0.7	79.8 ^c ± 0.3

Results are represented as mean ± standard deviation of three independent experiments.

Different letters in each row after the mean value are significantly different at 5% level according to Duncan's Multiple Range Test (DMRT).

Table 3
Biochemical constituents and mineral profiling of coconut haustorium based extrudates.^a

Parameters	100% R	50% R + 50% M	50% R + 40% M + 10% CH	50% R + 30% M + 20% CH	50% R + 20% M + 30% CH
Biochemical constituents (in %)					
Moisture	6.64 ^a ± 0.2	5.85 ^b ± 0.3	5.11 ^c ± 0.2	3.91 ^d ± 0.3	3.46 ^e ± 0.1
Ash	1.26 ^d ± 0.1	1.37 ^{dc} ± 0.1	1.50 ^{bc} ± 0.1	1.64 ^b ± 0.1	1.90 ^a ± 0.1
Available Carbohydrates ^b	80.1 ^a ± 2.5	71.2 ^c ± 2.6	73.5 ^{bc} ± 3.6	77.9 ^{ab} ± 1.9	78.2 ^{ab} ± 3.4
Oil	0.19 ^d ± 0.1	4.54 ^a ± 0.3	2.42 ^c ± 0.1	3.27 ^b ± 0.4	3.42 ^b ± 0.4
Protein	5.62 ^c ± 0.3	7.70 ^{ab} ± 0.1	7.17 ^b ± 0.5	8.00 ^a ± 0.7	8.17 ^a ± 0.4
Total soluble sugar	5.56 ^c ± 0.1	6.05 ^c ± 0.1	10.11 ^b ± 0.3	13.00 ^a ± 0.2	13.28 ^a ± 0.6
Mineral constituents (mg/100g)					
Potassium	41.33 ^c ± 2.5	99.67 ^d ± 3.5	167.67 ^c ± 4.2	215.67 ^b ± 7.0	297.33 ^a ± 9.9
Magnesium	29.22 ^c ± 0.2	87.50 ^d ± 0.6	103.00 ^c ± 0.8	111.35 ^b ± 0.9	124.91 ^a ± 1.0
Phosphorus	110.4 ^b ± 2.7	199.4 ^a ± 7.0	204.2 ^a ± 8.4	207.9 ^a ± 4.4	206.7 ^a ± 4.2
Calcium	42.02 ^d ± 0.3	85.02 ^a ± 1.2	84.69 ^a ± 0.6	74.36 ^b ± 0.2	63.02 ^c ± 0.5
Manganese	0.70 ^d ± 0.005	0.66 ^d ± 0.01	1.94 ^c ± 0.015	2.90 ^b ± 0.022	4.35 ^a ± 0.033
Iron	6.10 ^c ± 0.046	6.43 ^b ± 0.05	7.03 ^a ± 0.054	4.70 ^d ± 0.036	4.08 ^e ± 0.031
Copper	0.467 ± 0.074	0.404 ± 0.061	0.393 ± 0.058	0.408 ± 0.063	0.353 ± 0.053
Zinc	1.22 ^d ± 0.009	1.56 ^c ± 0.012	1.64 ^b ± 0.012	1.68 ^a ± 0.013	1.64 ^b ± 0.013

Results are represented as mean ± standard deviation of three independent experiments.

^a Except moisture other values are in dry weight basis of edible portion.

^b Monosaccharide equivalent. Different letters in each row after the mean value are significantly different at 5% level according to Duncan's Multiple Range Test (DMRT).

Table 4
Phenolics, flavonoids and antioxidant potential of coconut haustorium based extrudates.

Extrudates types	Phenolic content (mg GAE/100 g)	Flavonoid content (mg QE/100 g)	Antioxidant potential (mM TE/100 g)	
			CUPRAC	FRAP
100% R	20.9 ^d ± 0.9	7.94 ^d ± 2.44	0.17 ^e ± 0.02	0.087 ^d ± 0.01
50% R + 50% M	106.7 ^c ± 7.0	47.01 ^c ± 2.59	1.14 ^d ± 0.04	0.270 ^c ± 0.01
50% R + 40% M + 10% CH	182.7 ^b ± 2.8	53.58 ^c ± 4.40	1.38 ^c ± 0.08	0.364 ^{bc} ± 0.02
50% R + 30% M + 20% CH	200.9 ^{ab} ± 6.8	76.59 ^b ± 11.26	1.57 ^b ± 0.06	0.535 ^{ab} ± 0.13
50% R + 20% M + 30% CH	212.8 ^a ± 9.9	95.20 ^a ± 5.06	1.94 ^a ± 0.06	0.572 ^a ± 0.06

Results are represented as mean ± standard deviation of three independent experiments. GAE- Gallic acid equivalent; QE- Quercetin Equivalent; TE - Trolox equivalent; CUPRAC - CUPric Reducing Antioxidant Capacity; FRAP - Ferric Reducing Ability of Plasma; Different letters in each column after the mean value are significantly different at 5% level according to Duncan's Multiple Range Test (DMRT).

from 6.64% to 3.56% with the incorporation of haustorium. Ash content is the indirect indicator of minerals present in the extrudates, and it varied between 1.26% and 1.90%. The extrudates with the addition of haustorium showed higher ash content, and the increase was directly proportional to the amount of haustorium incorporated. Addition of haustorium to rice and maize blend led to significant increase in biochemicals in resultant extrudates. Available carbohydrate content in the 50% rice and 50% maize blend was 71.2 g. Replacement of maize with 10–30% haustorium caused gradual increase in available carbohydrates from 73.5 g to 78.2 g. Total soluble sugar content in the experimental extrudates was found significantly high compared to control extrudates based on rice and rice with maize. Since coconut haustorium contained about 44.2% of soluble sugar (Manivannan et al., 2016), the incorporation of haustorium increased the sugar content from 10.11% to

13.28% with 10–30% incorporation. The presence of high amount of soluble sugars, haustorium based extrudates offers natural sweetness to the products which were lacking in rice and maize based extrudates, suggesting that no further addition of sweeteners is required.

The total fat content ranged from 0.19% in 100% rice based extrudates to 4.54% in 50% Rice + 50% maize based extrudates. Maize is a good source of total fat (about 5%) compared to rice (which contain only about 0.5%), replacement of maize with haustorium significantly reduced the oil content to 2.42%, 3.27% and 3.42% with 10, 20 and 30% incorporation, respectively. The values obtained for total fat content is lesser than the theoretically calculated total fat content of the blends, and this was mainly due to the absorption of the oil in the extruder surface during extrusion and some amount of oil was lost while coming out from the die. Protein content in the extrudates varied

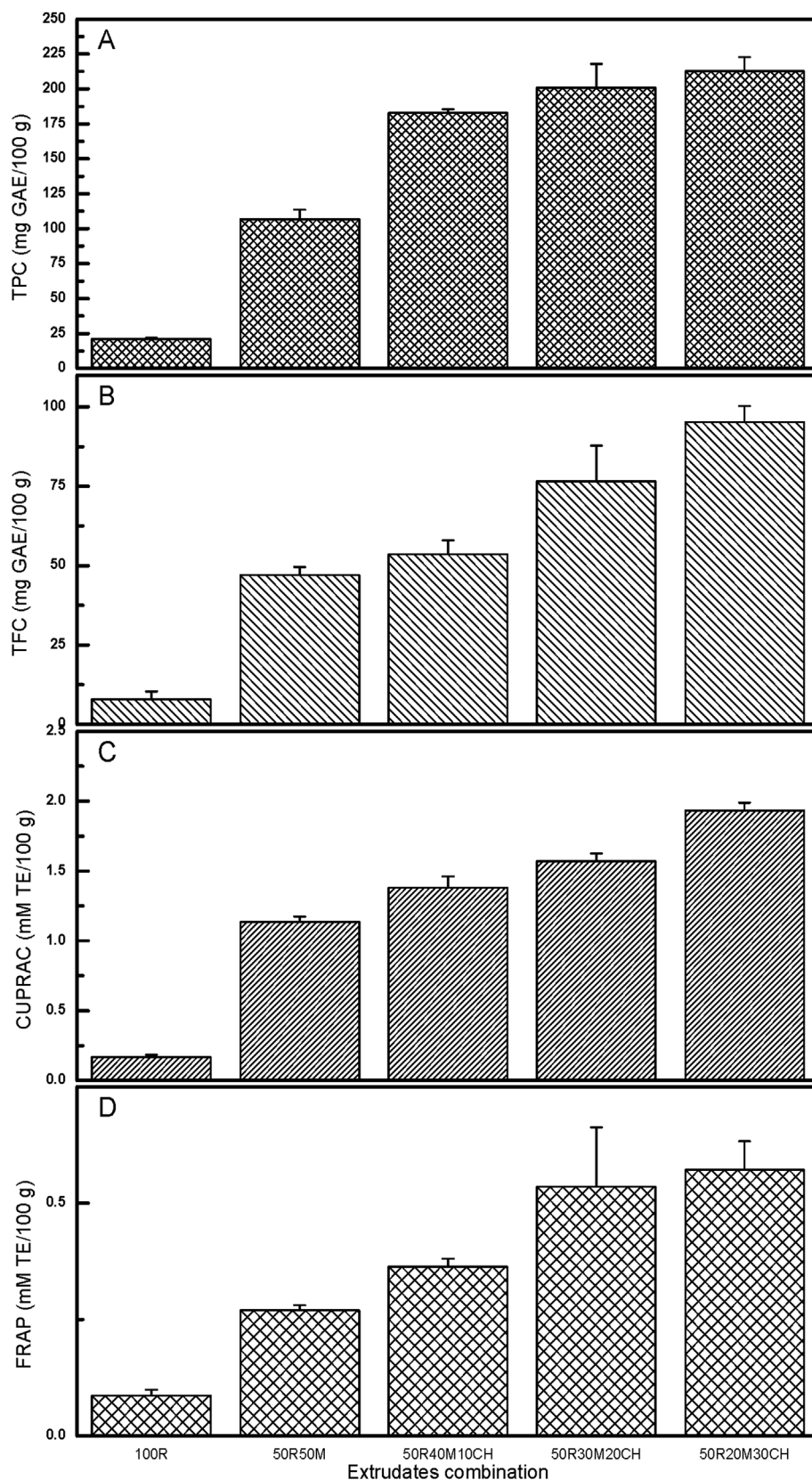


Fig. 2. Level of total phenolics, flavonoids and antioxidant potential of coconut haustorium based extrudates. Three independent experiments were performed and data are presented as mean \pm SD in 100 g sample; A- TPC - Total phenolic content, TPC was expressed as mg gallic acids equivalent (GAE); B- TFC - Total flavonoids content, TFC was expressed as mg quercetin equivalent (QE), C- CUPRAC and D- FRAP. CUPRAC and FRAP values are expressed as mM trolox equivalent (TE), obtained from a trolox solution having reducing power equivalent to that of 100 g sample. 100R - 100% Rice; 50R50M - 50% rice + 50% maize; 50R40M10CH - 50% rice + 40% maize + 10% coconut haustorium; 50R30M20CH - 50% rice + 30% maize + 20% coconut haustorium; 50R20M30CH - 50% rice + 20% maize + 30% coconut haustorium.

between 5.62% in 100% rice blend to 8.17% in 50% rice + 20% maize and 30% haustorium. A significant difference in protein content was observed between rice based extrudates and rice, maize and haustorium based extrudates. The protein content of maize and haustorium was almost same, so the replacement of maize with haustorium did not

show significant alteration in the protein content of the final product.

Significant differences were observed between the haustorium based extrudates for multiple macro and trace elements (Table 3). Except for copper, other minerals studied were significantly less in 100% rice based extrudates compared to other formulations. Among the

Table 5
Sensory attributes of coconut haustorium based extrudates.

Sensory attributes	100% R	50% R + 50% M	50% R + 40% M + 10% CH	50% R + 30% M + 20% CH	50% R + 20% M + 30% CH
Taste	5	6	7	8	8
Crispness	7	7	9	8	6
Odor	7	8	7	7	8
Chewiness	7	8	9	8	6
Color	8	8	9	8	8
Surface characteristics	7	7	8	9	7
Pore distribution	8	9	9	8	6
Average score	7.0	7.7	8.3	8.0	7.0

(Hedonic Scale: Dislike extremely-1; Dislike very much-2; Dislike moderately-3; Dislike slightly-4; Neither like nor dislike-5; Like slightly-6; Like moderately-7; Like very much-8; Like extremely-9).

macro mineral studied, potassium was rich in extrudates and its value ranged between 41.33 and 297.33 mg/100 g extrudates. Total phosphorus content varied between 110.4 and 207.9 mg/100 g extrudates. Magnesium and calcium content ranged from 29.22 to 124.91 mg and 42.02–85.02 mg/100 mL, respectively. Potassium content in the extrudates increased about 1.5, 2.2 and 3.0 times for 10–30% haustorium incorporated extrudates when compared to 50% rice + 50% maize based extrudates. Calcium content in 50% rice + 50% maize based extrudates was about 85.02 mg. Incorporation of haustorium significantly reduced the calcium content in the resultant product from 84.69 to 63.02 mg for 10–30% haustorium incorporation. Among the micro minerals studied, iron content was high and ranged from 4.08 mg to 7.03 mg, followed by manganese which ranged between 0.70 and 4.35 mg/100 g extrudates. Zinc and copper content ranged from 1.22 to 1.64 mg and 0.353–0.467 mg/100 g, respectively. Both macro and micro nutrients play a vital role in the various growth and developmental functions and act as a cofactor for various enzymes. Minerals like calcium and potassium are required for bone and teeth development. Incorporation of coconut haustorium significantly increased the minerals studied and thus improved the nutritional quality of the extrudates.

3.6. Phenolics, flavonoids, and antioxidant potential of coconut haustorium based extrudates

Phenolic content varied between 20.9 mg and 212.8 mg GAE (Table 4 & Fig. 2). Flavonoid content varied from 7.64 mg QE in 100% rice based extrudates to 95.2 mg QE in 30% haustorium incorporated extrudates. The antioxidant activity in terms of reducing power measured by FRAP and CUPRAC methods ranged from 0.087 to 0.17 mM TE for 100% rice to 0.572 and 1.94 mM TE for 30% haustorium incorporated extrudates, respectively. Coconut haustorium contained a considerable amount of phenolics with antioxidant potential, and its incorporation in the extrudates significantly increased antioxidant potential compared to controls.

3.7. Sensory attributes of resultant extrudates

The nutritional characteristics of the extrudates are a key consideration, but the extrudates need to have satisfactory organoleptic properties, which are deciding factors for overall acceptability. In general, overall acceptability of the extrudates depends mainly on the physical and sensory attributes, which are usually measured as density, expansion, taste and appearance (Dehghan-Shoar, Hardacre, & Brennan, 2010). These properties are related to the number and size of air cells formed during extrusion which is depend on the proportion and type of the starch. Sensory attributes of the base formula (100% rice and 50% rice + 50% maize) (7 and 7.7) were significantly

($P < 0.05$) improved by adding coconut haustorium (Table 5). Substantial improvements in sensory attributes especially taste, crispiness, chewiness which significantly increased with which the level of coconut haustorium up to 20% compared with the control. Adding coconut haustorium about 30% resulted in significant decrease in crispiness, chewiness, surface characteristics, and pore distribution. Thus incorporation coconut haustorium upto 20% has fair acceptability over the controls and 30% haustorium incorporated extrudates.

4. Conclusion

Extrusion provides a high-volume, low-cost alternative to conventional food processing methods. Improving the nutritional status of the rice and maize based extrudates is prime important to make them nutritionally superior. In this study, rice and maize based extrudates enriched with coconut haustorium, which is a rich source of nutrients, were prepared to enhance the nutritional status of the snack food. Incorporation of haustorium significantly improved the nutritional status and proved that it is an excellent source of phytonutrient especially phenolics and flavonoids with high antioxidant capacity. Haustorium addition has also influenced various physical, functional, color and sensory attributes. The resultant extrudates have the potential to replace the traditional snack foods which are low in nutrients. Based on the overall sensory acceptability and biochemical constituents, incorporation of 20% coconut haustorium in rice (50%) and maize (30%) based extrudates resulted in healthy and nutritious extrudates.

Conflict of interest

Authors do not have any conflict of interest.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.lwt.2017.10.049>.

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