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Evaluation of physicochemical, sensory, nutritional and textural properties of extruded rice (Hashemi variety) produced with carboxymethyl cellulose and locust bean gums

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ABSTRACT

The purpose of the extrusion process is to produce products with different shapes, textures, colors, and flavors to provide variety in foods and also to provide micronutrients. Therefore, the use of hydrocolloids and vitamins to improve the functional properties and nutritional value of extruded products is common. In this study, the effects of these gums at concentrations of 0.5%, 0.75%, and 1% (alone and in combination) and vitamin E at a dose of 400 mg/100g were evaluated for their physicochemical, sensory, nutritional, and textural properties in extruded rice. Vitamin E was added to all samples before the extrusion process and during the dry mixing stage. Based on the findings, the treatment including 1% locust bean gum and 1% CMC exhibited the maximum levels of moisture content (12.86%), ash (1.43%), density (0.397 g/cm^3), water absorption (4.87%), and solubility (20.54%), while the lowest values for these attributes were observed in the control treatment. In contrast, the control treatment exhibited the highest protein content (8.22%), while the treatment containing 0.5% locust bean gum showed the highest values for lateral extension (148.5%) and color change (15.13). In the cooked extruded rice, the treatment containing 1% carboxymethyl cellulose exhibited the highest rate of cooking loss (12.42%), while the treatment containing 1% locust bean gum and 1% carboxymethyl cellulose showed the highest hardness (24.42 N), chewability (28.78 N), vitamin E (60.2 mg/100g), and the lowest adhesiveness (2.51 mJ). Additionally, the control and combination treatments containing 0.5%, 0.75%, and 1% locust bean gum and CMC showed the highest scores (5) for sensory properties such as odor and taste, texture, and overall acceptance.

1- Introduction

Rice (*Oryza sativa* L.) is an annual plant belonging to the grass family which has numerous species. In Iran, rice is the second most important staple food after wheat and is obtained through a milling process. This process changes the textural and whiteness characteristics of rice, enhances its water-binding capacity, improves digestibility, and reduces cooking time. It is noteworthy that during the milling process, most of the minerals and vitamins in rice are lost, so it seems that by using the extrusion cooking technique and using broken rice as a cheap raw material and also as a suitable additive needed for specific groups, the complications caused by malnutrition can be eliminated and a functional product can be produced [1]. In this regard, various products have already been developed through the extrusion process [2, 3, 4, and 5]. Extrusion is a process in which raw material is forced under pressure through a small orifice to yield a product with desired shape and texture. During extrusion, several unit operations, including mixing, kneading, application of shear forces, heating, cooling, and shaping, occur simultaneously. In fact, the extrusion machine consists of a pump in which the input material is condensed and transformed into a semi-solid mass through various operations. This mass, due to the applied pressure, is ejected from the mold located at the end of the screw. The primary objective of extrusion is to diversify everyday foods by creating products with varying shapes, textures, colors, and flavors from the main food ingredients. Extrusion is a high-temperature, short-time (HTST) process that reduces microbial load and inactivates enzymatic activity. Advantages of extrusion include diversification of food products, reutilization of food waste, and lower processing costs compared to other cooking methods. Parameters such as temperature, pressure, die hole diameter, shear forces, and rheological properties of food are among the most important factors affecting the products obtained from the extrusion process. Notably, shear forces depend on the internal design of the body and the speed and shape of the screw. Initial moisture content and the chemical composition of raw materials, particularly the amount and type of starch, protein, fat, and sugars, affect the texture and color of the final extruded product [6]. The incorporation of hydrocolloids to improve the textural and functional properties of extruded foods is a common practice. Gums are hydrophilic polymers with high molecular weight, consisting of polysaccharides and, in some cases, proteins, which increase viscosity upon dissolution or dispersion in water [7]. Among the most important gums are locust bean gum and carboxymethyl cellulose. Carboxymethyl cellulose is a widely used gum derived from cellulose and is employed in both industrial and food applications. It is a linear, high-molecular-weight polymer that is water-soluble and carries a negative charge. Its viscosity is pH-insensitive, it is non-fermentable under normal conditions, and its ionic strength decreases with increasing temperature. Its stabilizing capacity is attributed to its high electronegativity, which enhances repulsion between particles. Today, this gum is used in various baked and extruded products to control viscosity, retain moisture, inhibit crystal growth, provide structural strength, maintain colloidal stability, improve moldability, enhance adhesion, and improve mouthfeel [8, 9]. Locust bean gum is the milled endosperm of locust bean seeds, which grow in regions with a Mediterranean climate. This gum is one of the seed-derived galactomannans, with a backbone composed of mannose units linked by β-(1→4) glycosidic bonds, wherein the hydrogen atom of the hydroxyl group on carbon number 6 is substituted by α-D-galactose units via (1→6) linkages. It appears as a white to cream-colored powder and consists primarily of high-molecular-weight hydrocolloid polysaccharides. It is dispersible in both cold and hot water, forming a sol with a pH ranging from 4.5 to 7, which can be converted into a gel upon addition of small amounts of sodium borate. Approximately 35% of locust bean constituents are simple-structured carbohydrates, and about 40% consist of complex-structured starch. The fat content of locust bean is very low, around 1%. Locust bean gum is widely used on an industrial scale as a thickener and stabilizer in food products [10]. Vitamin E is a fat-soluble vitamin found in plants, particularly in oilseeds and nuts. It possesses antioxidant properties and protects body tissues against the damaging effects of free radicals generated by certain chemical compounds. This vitamin is incorporated into the lipid layer of the cell membrane and within the cell, thereby preventing cellular membrane degradation. Naturally occurring vitamin E comprises four tocopherols and four tocotrienols, with alpha-tocopherol exhibiting the highest biological activity, followed by beta-tocopherol. Non-esterified tocopherols and tocotrienols are insoluble in water but readily soluble in alcohols and other organic solvents (including acetone, chloroform, and ether) as well as in vegetable oils. In the food industry, this vitamin is employed as an antioxidant in vegetable oils and fat-containing food products [11]. Developing a technology for producing extruded rice with quality and organoleptic characteristics comparable to natural rice, possessing equal or superior nutritional value, and at a lower production cost than natural rice, represents a valuable alternative. In this context, the present study investigated the feasibility of producing extruded rice using locust bean gum and carboxymethyl cellulose, along with the incorporation of vitamin E to enhance its functional properties and nutritional value.

2- Materials and Methods

2.1 Materials

In this study, raw materials including rice (Hashemi variety) with an amylose content of 21.7% (sourced from the local market), locust bean gum with an average molecular weight of 55,000 Da, carboxymethyl cellulose (CMC) with an average molecular weight of 41,000 Da (DOW Chemical Company, Germany), and vitamin E (Pouya Teb Company, Iran) were procured. Rice grains were ground using a hammer mill (Kenwood, Italy) and then passed through a 1 mm mesh sieve to achieve uniform particle size. Subsequently, their chemical characteristics, including moisture (AACC 44-16), ash (AACC 08-01), protein (AACC 46-12), fat (AACC 30-10), fiber (AACC 32-10), and amylose (AACC 40-18), were determined [12]. To prepare the dough, varying proportions of rice flour, locust bean gum, and carboxymethyl cellulose (0.5%, 0.75%, and 1.0%, individually and in combination), along with a fixed amount of vitamin E (400 mg/100 g), as outlined in Table 1, were mixed using a mixer (Bosch, Model MMB6145, Germany) at 365 rpm for 20 minutes. Water (16–30%) was then added to the mixture. Notably, a constant level of 1% emulsifier (diacetyl tartaric acid esters of monoglycerides, Pars Behbod Asia Company, Iran) was incorporated into all samples to improve product volume [13].

Table 1 Study treatments

Treatment	Code
Control [(raw rice grain; Hashemi variety)]	H0
Extruded rice, [0.5% locust bean gum (w/w flour basis) +Vitamin E (400mg/100g)]	H1
Extruded rice, [0.75% locust bean gum (w/w flour basis) +Vitamin E (400mg/100g)]	H2
Extruded rice, [1% locust bean gum (w/w flour basis) +Vitamin E (400mg/100g)]	H3
Extruded rice, [0.5% CMC gum (w/w flour basis) +Vitamin E (400mg/100g)]	H4
Extruded rice, [0.75% CMC gum (w/w flour basis) +Vitamin E (400mg/100g)]	H5
Extruded rice, [1% CMC gum (w/w flour basis) +Vitamin E (400mg/100g)]	H6
Extruded rice, 0.5% locust bean gum + 0.5% CMC gum (w/w flour basis) +Vitamin E (400mg/100g)]	H7
Extruded rice, [0.75% locust bean gum+ 0.75% CMC gum (w/w flour basis) +Vitamin E (400mg/100g)]	H8
Extruded rice, [1% locust bean gum+ 1% CMC gum (w/w flour basis) +Vitamin E (400mg/100g)]	H9

The extruder used (Jinan Saixi, China) was equipped with 16 to 32 circular dies, each with a diameter of 2.2 mm, and featured twin screws. It operated under a pressure range of 13.35–19.10 MPa, with screw speeds varying from 20 to 340 rpm and processing temperatures ranging from 75 to 95 °C. The extrusion conditions were set as follows: feed moisture content of 30%, screw speed of 26.6 rpm, feed rate of 11.5 $kg \cdot h^{-1}$, and temperature 95 °C. Upon exiting the extruder, the samples were conveyed via an air suction system through a tube into a dryer. The extruded samples were then dried in a single layer using hot-air convection at 50 °C until their moisture content reached 10–14 % (wet basis). Finally, the dried samples were packaged in polyethylene bags and coded for further analysis.

2-2. Tests Conducted on the Extruded Rice Samples (Before and After Cooking)

2-2-1- Moisture Content (Before cooking)

Moisture content was determined according to the standard AACC method No. 44-16 and using Equation (1) [12]:

$$MC = \frac{W_i - W_f}{W_i} \times 100$$

(1)

Where: MC = Moisture content (wet basis (%)), W_i = Initial wet weight (kg), and W_f = Dry weight (kg).

2-2-2- Ash Content (Before cooking)

Ash content was determined according to the standard AACC method No. 08-01 [12]. For this purpose, 5 g of each sample was placed in a porcelain crucible and charred over a gas flame. After the organic components were completely burned off, the crucible containing the residue was transferred into an electric muffle furnace maintained at approximately 550–600 °C and heated until the contents turned white and a constant weight was achieved. The ash percentage was then calculated based on the weight difference before and after incineration in the furnace.

2-2-3- Protein Content (Before cooking)

Protein content of the extruded rice samples was determined according to the standard AACC method No. 46-12 [12]. This method is based on the oxidation of organic matter in the sample using concentrated sulfuric acid in the presence of a catalyst. In this process, all nitrogen in the sample is converted to ammonium sulfate, $(NH_4)_2SO_4$. Subsequently, ammonia is liberated by adding an alkali, distilled, and absorbed into a known volume of standard acid. The amount of nitrogen in the sample is then calculated by back-titration of the absorbed ammonia. Finally, the protein content is obtained by multiplying the nitrogen content by the appropriate conversion factor for rice flour, as expressed in Equation (2):

$$P = \frac{A-B}{100} \times 0.1 \times 14 \times 57$$

(2)

Where: P = Protein content (%), A = volume (mL) of sulfuric acid consumed for the sample, and B = volume (mL) of sulfuric acid consumed for the control.

2-2-4- Water Absorption (Before cooking)

2.5 g of ground sample (particle size reduced to 200–250 μ) was dispersed in 25 g of distilled water and stirred with a glass rod for 30 min. The resulting dispersion was transferred into centrifuge tubes and centrifuged at 4,000 rpm for 15 min. The sedimented phase was then weighed to determine the water absorption capacity [14].

2-2-5- Lateral Expansion (Before cooking)

Lateral expansion (LE) of the extruded rice samples was calculated using Equation (3) [14]:

$$LE = \frac{d}{d_0} \times 100$$

(3)

Where: d_0 = Mold hole diameter (mm), and d = Diameter of the extruded rice (mm).

2-2-6- Bulk Density (Before cooking)

Bulk density was determined according to the standard AACC method No. 54-20. After drying the extruded rice (10 % (dry basis), the grains were allowed to fall freely from a height of 15 cm into a container of known volume. The surface of the rice in the container was leveled using a zigzag motion with a straightedge. The mass of rice in the container was then recorded, and bulk density was calculated in kg/m³ using Equation (4):

$$\rho_b = \frac{m_b}{v_b}$$

(4)

Where: ρ_b= Bulk density (kg/m³), m_b = Mass of the sample (kg), and v_b= Volume of the container (m³) [15].

2-2-7- Solubility (Before cooking)

In this test, 2.5 g of ground sample (particle size reduced to 200–250 µ) was dispersed in 25 g of distilled water and stirred with a glass rod for 30 min. The dispersion was transferred into centrifuge tubes and centrifuged at 4,000 rpm for 15 min. The supernatant was then separated, and the solubility index was determined based on the dissolved solids in the supernatant [14].

2-2-8- Color Changes (ΔE) (Before cooking)

Total color changes of the extruded rice were measured using a HunterLab according to the standard AACC method No. 14-10 [12]. The color changes (ΔE) were calculated using Equation (5):

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2}$$

(5)

Where: L_0^* , a_0^* and b_0^* belong to the control sample.

2-2-9- Cooking Loss

100 g of extruded rice was immersed in 300 mL of boiling water for 13 min. After draining, the separated cooking water was collected in a beaker and placed in an oven at 115 °C for 1 hour to ensure complete evaporation of water. The mass of the remaining dried solids was then measured and reported as cooking loss [14].

2-2-10- Texture Analysis

Texture profile analysis of the extruded samples was performed using a Brookfield texture analyzer (Model CT3 Pro, USA). In this procedure, 40 g of cooked sample was placed in a circular container and compressed to 60 % of its original height using a cylindrical probe (TA5) at a speed of 0.5 mm/s. Hardness, adhesiveness, and chewiness were determined from the resulting force–deformation curves [16].

2-2-11- Sensory Evaluation

Sensory evaluation was conducted using a 5-point hedonic scale by a trained panel of 10 assessors (male and female, aged 20–30 years). For each attribute, a score of 5 represented “excellent” and 1 indicated “very poor.” The evaluation included aroma and flavor, texture, and overall acceptability [14].

2-2-12- Vitamin E Determination in Cooked Extruded Rice Samples

Vitamin E content was analyzed using an HPLC system (Pharmacia LKB) equipped with a UV multi-wavelength detector (Model 2241) and a Super Pac Pep-S column. The mobile phase flow rate was set at 1 mL/min, and an injection volume of 50 µL was used over a 10-min run time. The detection wavelength was set at 325 nm from the start of the run until 7 min, and then switched to 292 nm from 7 to 150 min. After separation, chromatograms were interpreted using HPLC Manager and Nelson software for peak identification and quantification [17].

2-2-13- Statistical Analysis

Data were analyzed using a completely randomized design with three replications. Mean comparisons were performed using Duncan’s multiple range test at a 5 % significance level ($p \leq 0.05$) using SPSS 16.

3-Results and Discussion

According to the chemical analyses performed on rice flour (Hashemi variety), the following values were obtained: moisture content 9.18 %, total ash 0.41 %, protein 8.32 %, fat 0.21 %, fiber 2.5 %, and amylose 26.91 %. These results indicate that the Hashemi rice variety is suitable for the production of extruded rice.

3-1- Physicochemical Analyses of Control and Extruded Rice Samples (Before cooking)

The mean comparison of data regarding the effects of different levels of locust bean gum and carboxymethyl cellulose (CMC) on the physicochemical properties of extruded rice samples, compared to the control, is presented in Table 2.

Table 2 Mean comparison of physicochemical analysis of extruded rice and control samples (before cooking)

Treatment	Moisture (%)	Ash (%)	Protein (%)	Water absorption (%)
H0	8.00±0.10 e	0.42±0.05 f	8.22±0.11 a	2.10±0.13 g
H1	10.57±0.15 d	0.61±0.03 e	7.90±0.10 b	2.35±0.15 fg
H2	10.86±0.17 cd	0.79±0.03 d	7.84±0.10 b	2.80±0.15 e
H3	11.59±0.18 b	1.11±0.05 c	7.50±0.05 c	3.35±0.15 d
H4	11.00±0.11 c	0.64±0.04 e	7.90±0.10 b	2.56±0.18 ef
H5	11.48±0.16 b	0.79±0.03 d	7.84±0.10 b	3.27±0.12 d
H6	11.67±0.15 b	1.26±0.03 b	7.51±0.05 c	3.45±0.10 d
H7	12.63±0.21 a	1.28±0.03 b	7.51±0.05 c	3.88±0.08 c
H8	12.74±0.18 a	1.35±0.05 a	7.42±0.05 cd	4.35±0.10 b
H9	12.86±0.15 a	1.43±0.08 a	7.35±0.05 d	4.87±0.11 a

In each column, mean that at least one letter in common, according to Duncan's test, not significant difference at 5%

Continuation of Table 2 Mean comparison of physicochemical analysis of extruded rice and control samples (before cooking)

Treatment	Lateral extension (%)	Density (g/cm^3)	Solubility in water (%)	ΔE
H0	-	0.76±0.02 d	15.26±0.13 g	0
H1	148.5±3.4 a	0.78±0.02 d	16.43±0.15 f	15.13±0.08 a
H2	138.31±2.5 b	0.81±0.03 cd	17.32±0.15 e	9.44±0.20 b
H3	135.58±2.3 b	0.85±0.02 bc	19.54±0.18 c	8.53±0.11 c
H4	130.08±2.1 c	0.79±0.03 d	17.14±0.17 e	9.78±0.18 b
H5	127.11±2.3 c	0.81±0.03 cd	18.27±0.15 d	9.40±0.22 b
H6	126.53±2.1 c	0.86±0.03 bc	19.65±0.18 c	8.50±0.12 c
H7	120.57±1.9 d	0.89±0.03 b	19.86±0.20 bc	8.38±0.12 c
H8	120.08±1.6 d	0.89±0.03 b	20.24±0.24 ab	7.68±0.15 d
H9	113.21±1.8 e	0.97±0.05 a	20.54±0.25 a	7.95±0.18 d

In each column, mean that at least one letter in common, according to Duncan's test, not significant difference at 5%

3-1-1- Moisture Content

According to the Iranian National Standard No. 2814, the moisture content of rice should be within the range of 10–14 % to prevent mold growth [18]. As shown in Table 2, a statistically significant difference ($p \leq 0.05$) was observed among treatments regarding their effect on the moisture content of extruded rice samples. The highest moisture content (12.86 %) was recorded in treatment H9, while the lowest value (8.00 %) was observed in treatment H0. The results indicate that increasing the levels of locust bean gum and CMC led to higher moisture retention in the samples. This effect can be attributed to the hydrocolloid molecular structure and the hydrophilic nature of these gums, which enhance water-holding capacity, reduce free water molecules, and consequently inhibit amylopectin recrystallization. Furthermore, improved dough quality and favorable rheological properties were achieved. Additionally, the higher moisture content in CMC-containing treatments can be explained by the greater number of hydroxyl groups in CMC compared to locust bean gum. Starch damage occurring during extrusion may also contribute to increased water absorption capacity [19, 20].

3-1-2- Ash

As indicated in Table 2, a statistically significant difference ($p \leq 0.05$) was observed among treatments in terms of their effect on ash content. The highest ash content (1.43 %) was measured in treatment H9, whereas the lowest value (0.42 %) was found in treatment H0. The results demonstrate that, across all treatments, increasing the levels of locust bean gum and CMC significantly increased ash content. This increase is likely due to the presence of mineral elements as well as minor amounts of tannins and tannosides in the gums used [14, 21].

3-1-3- Protein

According to Table 2, a statistically significant difference ($p \leq 0.05$) was observed among the different treatments regarding their effect on the protein content of extruded rice samples. The highest protein content (8.22 %) was measured in treatment H0, while the lowest value (7.35 %) was recorded in treatment H9. The results indicate that, across all treatments, increasing the levels of locust bean gum and carboxymethyl cellulose (CMC) led to a significant decrease in protein content. Generally, the extrusion process enhances protein digestibility by denaturing proteins, which increases the accessibility of enzymatic cleavage sites within the protein structure. Many enzymes and anti-nutritional factors lose their activity during extrusion due to protein denaturation. The extent of protein denaturation is commonly assessed by measuring protein solubility in water or similar solvents. Protein solubility typically increases under high shear conditions and is also influenced by temperature and moisture content [19, 20]. Hazarika et al. (2013) reported that high temperature and low moisture promote Maillard reactions. Reducing sugars (small saccharides formed under high shear) and sucrose (after hydrolysis) can react with lysine, thereby reducing the nutritional value of proteins in extruded products [21].

4-1-3- Water Absorption Capacity

As shown in Table 2, a statistically significant difference ($p \leq 0.05$) was observed among treatments in terms of their effect on water absorption capacity of extruded rice samples. The highest water absorption (4.87 %) was recorded in treatment H9, whereas the lowest value (2.10 %) was observed in treatment H0. Generally, a higher water absorption index indicates greater starch degradation into smaller components and, consequently, a higher degree of gelatinization. Hydrocolloid gums enhance water absorption and promote starch swelling, thereby increasing the extent of gelatinization. Becker et al. (2014), in a study on the physicochemical properties of restructured rice, reported that water absorption increases with the degree of starch gelatinization. This occurs because more hydroxyl groups become available to form hydrogen bonds with water molecules, thereby enhancing water uptake [6]. Ravindran et al. (2011) investigated the effects of guar gum, locust bean gum, and fenugreek gum at varying concentrations in extruded rice–chickpea flour blends. Their results showed that increasing guar and locust bean gum concentrations up to 5 % significantly increased water absorption, whereas further increases beyond 5 % led to a significant reduction. They attributed the increased water absorption during thermal processing to protein denaturation, starch gelatinization, and fiber swelling [14]. Liu et al. (2011) reported that, based on response surface methodology, optimal extrusion conditions included 30 % feed moisture, screw speed of 26.6 rpm, extrusion temperature of 95 °C, and 4 % rice bran combined with guar gum. Their findings indicated that water absorption increased with higher feed moisture and screw speed, but decreased with increasing extrusion temperature. They explained that moisture acts as a plasticizer, reducing starch granule breakdown and thereby enhancing water absorption capacity [16].

5-1-3- Lateral Expansion

According to Table 2, a statistically significant difference ($p \leq 0.05$) was observed among treatments regarding their effect on lateral expansion of extruded rice samples. The highest lateral expansion (148.5 %) was observed in treatment H1, while the lowest value (113.21 %) was recorded in treatment H9. In general, higher moisture content in the feed reduces vapor pressure during extrusion, which is expected to increase the elasticity of the extrudate and consequently reduce lateral expansion. Furthermore, compared to locust bean gum, the higher water-holding capacity of carboxymethyl cellulose softens the amylopectin structure, improving the elasticity of the extruded rice and resulting in a more pronounced reduction in lateral expansion [20, 22]. Liu et al. (2011) studied the physicochemical and textural properties of extrusion-cooked shaped rice, incorporating rice bran at zero and 4% levels. Extrusion was performed under varying conditions: feed moisture (26.6–33.4 %), screw speed (20.1–32.6 rpm), and temperature (70–120 °C). Their results showed that increased feed moisture altered the amylopectin molecular structure, reduced melt elasticity, and consequently decreased expansion, while bulk density increased. They reported lateral expansion values ranging from 139 to 210 and noted that both higher extrusion temperature and increased screw speed significantly reduced lateral expansion. High screw speeds caused starch molecule scission, reduced dough elasticity, and ultimately decreased expansion [16]. Becker et al. (2014) also indicated that the protein and fat content of the feed material influence lateral expansion. Proteins reduce expansion by modulating water distribution during extrusion, while fats act as lubricants and protect starch granules from gelatinization, thereby decreasing expansion [6].

6-1-3- Density

As shown in Table 2, a statistically significant difference ($p \leq 0.05$) was observed among treatments regarding their effect on the bulk density of extruded rice samples. The highest bulk density (0.97 g/cm³) was recorded in treatment H9, while the lowest value (0.76 g/cm³) was observed in treatment H0. As previously mentioned, the addition of gums reduced lateral expansion, which typically contributes to lower bulk density. However, higher gum concentrations enhance water absorption capacity more effectively, and due to structural modifications in amylopectin, they ultimately increase bulk density [19, 22]. Wang et al. (2013) investigated the effects of emulsifiers and hydrocolloids on certain quantitative and qualitative properties of extruded rice and reported that hydrocolloid addition increased water solubility index, bulk density, water absorption, and adhesiveness. They explained that bulk density reflects the ability of extruded products to sink or float in water; specifically, higher gelatinization and reduced lateral expansion lead to increased bulk density [22].

7-1-3- Solubility Index

Table 2 indicates a statistically significant difference ($p \leq 0.05$) among treatments in terms of their effect on the solubility index of extruded rice samples. The highest solubility (20.54 %) was observed in treatment H9, whereas the lowest value (15.26 %) was recorded in treatment H0. The water solubility index is an important indicator of physical and chemical changes during extrusion, reflecting the hydrophilic–hydrophobic nature of the sample's constituents and particularly correlating with the extent of starch degradation during extrusion cooking. As noted earlier, gum-containing treatments exhibited higher moisture content compared to the control. Consequently, their higher solubility can be attributed to greater starch granule gelatinization and disruption. In other words, increased solubility signifies more extensive starch breakdown in extruded rice. Additionally, this outcome may result from interactions among gums themselves and between gums and starch, leading to the formation of complex active structures that enhance solubility [16, 20, 22]. Ravindran et al. (2011) evaluated the effects of guar, locust bean, and fenugreek gums at varying concentrations on extruded rice–chickpea flour blends and demonstrated that increasing gum concentration elevated the water solubility index [14].

8-1-3- Color Changes

As indicated in Table 2, a statistically significant difference ($p \leq 0.05$) was observed among treatments regarding their effect on color changes (ΔE) of extruded rice samples. The highest ΔE value (15.13) was recorded in treatment H1, while the lowest (7.68) was observed in treatment H8. According to the findings, increasing sample moisture content significantly reduced overall color changes

(ΔE). The intensification of color is primarily attributed to non-enzymatic browning (Maillard reaction), caramelization, protein degradation, and pigment breakdown during extrusion. It is noteworthy that increasing temperature and decreasing humidity, promote Maillard reactions, leading to the formation of dark pigments, particularly melanoidins. Additionally, thermal degradation of heat-sensitive compounds such as carbohydrates, proteins, and vitamins can also contribute to color alterations [20].

2-3- Results of Tests Conducted on Control and Extruded Rice Samples (After cooking)

Table 3 presents the mean comparison of data regarding the effects of locust bean gum and carboxymethyl cellulose (CMC) on textural properties and vitamin E content of cooked extruded rice samples compared to control samples.

Table 3 Mean comparison of cooking loss, textural analysis, and vitamin E of extruded rice and control samples (after cooking)

Treatment	Cooking loss (%)	Texture hardness (N)	Chewiness (N)	Adhesiveness (mJ)	Vitamin E (mg/100g)
H0	7.90±0.04 f	7.84±1.09 g	3.70±0.23 i	2.51±0.05 a	5.1±0.88 g
H1	8.74±0.05 e	8.75±1.05 g	5.00±0.89 h	0.22±0.02 b	20.2±1.2 f
H2	10.63±0.08 c	10.59±1.07 f	5.41±0.15 h	0.25±0.02 b	22.1±1.18 f
H3	9.46±0.09 d	13.89±1.80 de	14.19±1.11 d	0.20±0.03 bc	33.2±1.33 de
H4	11.78±0.18 b	9.80±1.31 fg	6.50±0.65 g	0.23±0.02 b	20.3±1.14 f
H5	8.72±0.06 e	11.87±1.85 ef	9.18±1.08 e	0.18±0.02 c	32.2±1.08 e
H6	12.42±0.23 a	15.34±1.13 d	7.96±1.15 f	0.20±0.03 bc	35.2±1.71 d
H7	7.94±0.03 f	18.74±1.06 c	23.21±1.36 b	0.13±0.02 d	48.3±1.65 c
H8	7.93±0.04 f	20.23±1.07 b	18.20±1.85 c	0.18±0.02 c	53.3±1.47 b
H9	7.93±0.04 f	24.42±1.05 a	28.78±2.01 a	0.10±0.01 d	60.2±1.55 a

In each column, mean that at least one letter in common, according to Duncan's test, not significant difference at 5%

2-3-1- Cooking Loss

As shown in Table 3, a statistically significant difference ($p \leq 0.05$) was observed among treatments in terms of cooking loss. The highest cooking loss (12.42 %) occurred in treatment H6, while the lowest (7.90 %) was recorded in treatment H0. Generally, extrusion conditions—such as mechanical and thermal energy (screw speed and extrusion temperature)—enhance gelatinization of extruded materials. Additionally, variations in feed moisture, blade speed, and feed rate also influence extrudate texture. Moreover, formulation composition significantly affects the final product's texture. Therefore, the observed cooking loss—resulting from the creation of a novel product—is expected and can be minimized through optimization of process conditions and formulation to approach the characteristics of natural rice. According to the results, the moisture content of extruded rice samples increased with increasing gum concentration. Consequently, treatments with higher moisture exhibited greater cooking loss. This is because increased water absorption promoted starch gelatinization and granule disintegration, leading to higher solids leaching during cooking. Similar findings have been reported by other researchers [19, 23].

2-3-2- Hardness

Table 3 shows a statistically significant difference ($p \leq 0.05$) among treatments regarding hardness. The highest hardness (24.42 N) was recorded in treatment H9, while the lowest (7.84 N) was observed in treatment H0. The primary cause of increased hardness is the pressure applied during extrusion, which restricts lateral expansion and increases density and compactness of the structure. Treatment H9, with higher moisture, lower lateral expansion, and stronger amylose–gum complexes, developed a harder texture under extrusion pressure compared to other treatments [20, 22]. Wang et al. (2013) reported that emulsifier addition increased gelatinization but reduced water solubility index, adhesiveness, and stickiness, whereas gum addition increased water solubility index, bulk density, water absorption, and hardness. They attributed this to the formation of starch–emulsifier–gum complexes, which increased the density of extruded rice grains compared to the control, thereby enhancing hardness [22].

2-3-3- Chewiness

A statistically significant difference ($p \leq 0.05$) was observed among treatments in chewiness (Table 3). The highest chewiness (28.78 N) was recorded in treatment H9, and the lowest (3.70 N) in treatment H0. The higher chewiness in H9 can be attributed to greater textural uniformity and reduced lateral expansion. Additionally, CMC-containing samples exhibited more favorable chewiness than locust bean gum samples due to their higher viscosity [20].

2-3-4- Adhesiveness

As shown in Table 3, a statistically significant difference ($p \leq 0.05$) was observed among treatments regarding adhesiveness. The highest adhesiveness (2.51 mJ) was recorded in treatment H0, while the lowest (0.10 mJ) was observed in treatment H9. Thus, the incorporation of locust bean gum and CMC reduced post-cooking adhesiveness compared to the control. This reduction is likely due to greater amylose leaching from the starch matrix, which diminishes stickiness. Sirirat et al. (2005), in a study on extrusion-cooked rice-based vermicelli, reported that adding monoglyceride emulsifier forms complexes with amylose, preventing its leaching during starch gelatinization. This allows starch granules to swell in hot water, reducing water absorption capacity and, consequently, adhesiveness [24].

2-3-5- Vitamin E Content

Table 3 shows a statistically significant difference ($p \leq 0.05$) among treatments in vitamin E content. The highest level (60.2 mg/100 g) was found in treatment H9, while the lowest (5.1 mg/100 g) was in treatment H0. In other words, the use of locust bean gum and CMC in extruded rice samples enhanced the retention and stability of vitamin E compared to the control. Generally, micronutrient stability in fortified foods depends on several factors, including fortification method, micronutrient properties, washing, and cooking conditions. Extrusion is a high-temperature, short-time (HTST) process, and the nutritional value of the final product is influenced by temperature, feed moisture, processing time, oxygen availability, light, pH, screw speed, and die diameter. Other studies have similarly shown that high extrusion temperatures combined with low feed moisture significantly reduce the nutritional value of food products [14, 19].

3-3- Sensory Evaluation of Control and Extruded Rice Samples (After cooking)

Table 4 presents the mean comparison of data on the effects of locust bean gum and CMC on the sensory attributes of cooked extruded rice compared to the control.

Table 4 Mean comparison of organoleptic properties of extruded rice and control samples (after cooking)

Treatment	Flavor	Texture	Overall acceptability
H0	5±0.2 a	5±0.2 a	5±0.2 a
H1	3±0.1 c	3±0.3 c	3±0.2 c
H2	3±0.1 c	3±0.3 c	3±0.2 c
H3	4±0.3 b	3.5±0.2 bc	3.5±0.3 bc
H4	3±0.1 c	4±0.3 b	3.5±0.3 bc
H5	4±0.3 b	4±0.3 b	4±0.3 b
H6	4±0.3 b	4±0.3 b	4±0.3 b
H7	5±0.2 a	5±0.2 a	5±0.2 a
H8	5±0.2 a	5±0.2 a	5±0.2 a
H9	5±0.2 a	5±0.2 a	5±0.2 a

In each column, mean that at least one letter in common, according to Duncan's test, not significant difference at 5%

3-3-1- Aroma and Flavor

As shown in Table 4, a statistically significant difference ($p \leq 0.05$) was observed among treatments regarding aroma and flavor. The highest score (5) was assigned to treatments H0, H7, H8, and H9, while the lowest (3) was given to H1, H2, and H4. The superior aroma and flavor in these treatments may be linked to the gums used, as these attributes are influenced by caramelization and Maillard reactions, which gums can enhance [25]. It appears that in the high-scoring treatments, non-enzymatic browning occurred at an optimal level, contributing positively to sensory perception.

3-3-2- Texture

A statistically significant difference ($p \leq 0.05$) was observed among treatments in texture evaluation (Table 4). The highest score (5) was assigned to treatments H0, H7, H8, and H9, while the lowest (3) was given to H1 and H2. As previously noted, treatments H8 and H9 had higher moisture content, which reduces lateral expansion during extrusion, resulting in a denser, more compact texture. Moreover, at higher moisture levels, starch granules gelatinize more rapidly, contributing to increased firmness and a more desirable texture. The results also indicate that, for each gum type, increasing its concentration enhanced sample firmness, with CMC-containing samples exhibiting greater hardness due to increased viscosity and more extensive starch gelatinization [26].

3-3-3- Overall Acceptability

Table 4 shows a statistically significant difference ($p \leq 0.05$) among treatments in overall acceptability. The highest score (5) was assigned to treatments H0, H7, H8, and H9, while the lowest (3) was given to H1 and H2. Considering all sensory attributes collectively, treatments H7, H8, and H9, containing varying levels of locust bean gum and CMC, achieved overall acceptability scores comparable to the control (H0). This suggests that the incorporation of these hydrocolloids played a significant and beneficial role in producing extruded rice with improved sensory properties as a novel food product.

4- Conclusion

The objective of this study was to develop a synthetic rice formulation with quality and organoleptic characteristics similar to natural rice, using locust bean gum and carboxymethyl cellulose, while enhancing its nutritional value through vitamin E fortification. The results demonstrated that varying levels of these gums improved the physicochemical, textural, and sensory properties of extruded rice compared to the control. The optimal formulation, containing 1% locust bean gum, 1% CMC, and 400 mg/100 g vitamin E, was identified as the best treatment. These findings suggest that the developed formulation can be effectively applied in the production of nutritionally enriched extrusion-cooked rice, offering improvements in quality, texture, and nutritional profile.

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مقاله علمی_پژوهشی

ارزیابی ویژگی‌های فیزیکو- شیمیایی، حسی، تغذیه‌ای و بافت برنج (رقم هاشمی) اکسترود تولید شده با صمغ‌های کربوکسی متیل سلولز و خرنوب

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چکیده

هدف از فرآیند اکستروژن، تولید محصولاتی با شکل، بافت، رنگ و طعمی متفاوت به‌منظور ایجاد تنوع در غذاهای روزمره و همچنین تامین ریزمغذی‌ها است. لذا استفاده از هیدروکلوئیدها و ویتامین‌ها ه‌منظور بهبود ویژگی‌های عملکردی و ارزش تغذیه‌ای فرآورده‌های روزن‌رانی شده مرسوم می‌باشد. در ین راستا در پژوهش حاضر تاثیر صمغ‌های لوکاست و کربوکسی متیل سلولز در سطوح (۰/۵، ۰/۷۵ و ۱ درصد) و ویتامین E به میزان ۴۰۰ mg/100g، بر ویژگی‌های فیزیکو-شیمیایی، بافت، تغذیه‌ای و حسی برنج اکسترود شده رقم هاشمی مورد بررسی قرار گرفت. افزودن ویتامین E در تمام نمونه‌ها قبل ز فرایند اکستروژن و در مرحله مخلوط کردن خشک انجام پذیرفت. طبق نتایج، بیشترین میزان رطوبت (۱۲/۸۶٪)، خاکستر (۱/۴۳٪)، جذب آب (۴/۸۷٪)، دانسیته (۰/۹۷g/cm^3) و حلالیت (۲۰/۵۴٪) در تیمار ترکیبی حاوی (۱ درصد صمغ خرنوب و ۱ درصد صمغ کربوکسی متیل سلولز) و کمترین مقادیر مربوط به این صفات در تیمار شاهد اندازه‌گیری شد. اما بیشترین مقدار پروتئین (۸/۲۲٪) در تیمار شاهد و بیشترین میزان گسترش جانبی (۱۴۸/۵٪) و تغییرات رنگ (۱۵/۱۳) در تیمار حاوی ۰/۵ درصد صمغ خرنوب تعیین گردید. از سوی دیگر، بیشترین میزان افت پخت (۱۲/۴۲٪) در تیمار حاوی ۱ درصد صمغ کربوکسی متیل سلولز و بیشترین میزان سختی (۲۴/۴۲N)، قابلیت جوندگی (۲۸/۷۸N)، ویتامین E (۶۰/۲ mg/100g) و کمترین میزان چسبندگی (۲/۵۱mJ) در تیمار ترکیبی حاوی (۱ درصد صمغ خرنوب و ۱ درصد صمغ کربوکسی متیل سلولز) به دست آمد. همچنین بیشترین امتیاز (۵) خواص حسی در تیمارهای شاهد و تیمارهای ترکیبی حاوی ۰/۵، ۰/۷۵ و ۱ درصد صمغ خرنوب و کربوکسی متیل سلولز مشاهده شد.