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Papaya Rind as Natural Tenderizer in the Development of Functional Restructured Goat Meat Blocks

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ABSTRACT

The present study was conducted to evaluate the effect of incorporating papaya rind powder (PRP) on the development of functional restructured goat meat blocks (RGMB). Based on preliminary trials, three different levels of PRP (1%, 2%, and 3%) were added to the formulation by replacing goat meat, resulting in four samples: Control (without PRP), T1 (with 1% PRP), T2 (with 2% PRP), and T3 (with 3% PRP). The samples were assessed for various physico-chemical, proximate, colour, texture, and sensory attributes. The incorporation of PRP significantly ($p<0.05$) improved the cooking yield and crude fibre content of the developed products. PRP incorporation significantly improved the hardness and reduced the chewiness score. Increasing levels of PRP resulted in darker product colour, reflected by decreased L^* values and increased b^* values. The sensory attributes of the functional RGMB improved with the addition of PRP up to 2% levels; thereafter, a marked deterioration of the sensory qualities was observed. The overall acceptability of functional RGMB formulated with 2% PRP was recorded as the highest. Thus, good-quality functional RGMB could be prepared by adding 2% PRP.

HIGHLIGHTS

- Good quality restructured goat meat blocks prepared with 2% papaya rind powder.
- Papaya rind incorporation improved the crude fibre content.

Keywords: Restructuring, goat meat, papaya rind, quality attributes

Goat is an ideal small ruminant for meat production due to its hardy nature, prolificity, minimal competition with other livestock in terms of feeding, resistance, adaptation to harsh climatic conditions and ability to thrive and produce even at minimal inputs (Umaraw *et al*., 2017). Goat meat is widely preferred worldwide due to its high nutritive value and lower cholesterol levels than other types of meat (Ismail *et al*., 2025). It does not have any social taboo and is universally accepted across various cultures, societies, and religious sects. Furthermore, it has lower calorific values, high-quality animal proteins comprising all essential amino acids, a desirable fatty acid profile, and is high in minerals such as iron and potassium and lower in sodium (Watkins *et al*., 2021; Kumar *et al*., 2023). Goat meat contains a high amount of connective tissue, resulting in its higher toughness and stringiness (Kumar *et al*., 2024). In addition to this, other factors such as the use of spent/ culled and old animals for meat production, improper preslaughter handling, improper management, care, and nutrition also affect the tenderness, nutritive quality, and consumer acceptance of the meat (Sobri *et al*., 2023).

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Various technological interventions such as restructuring, ultrasonication, marination, etc, are applied to improve the meat quality, tenderness, and overall acceptability of goat meat (Sobri *et al*., 2023; Kumar *et al*., 2024; Awad *et al*., 2024). Restructured meat products are made by effectively utilizing low-value carcass cuts, trimmings, and tough meat from the slaughter of spent or culled animals, which is achieved through blade tenderization, massaging, and tumbling. Thus, this technology has been used to produce good-quality goat meat products (Gadekar *et al.,* 2014a, b; 2017). Furthermore, various tenderizers are applied in meat processing to enhance the tenderness, texture, acceptability, and juiciness of the meat, such as by applying calcium chloride or utilizing tenderizing enzymes present in plants, such as papain, ficin, or bromelin (Kantale *et al*., 2019). With the increasing preference for natural or green consumerism, the use of natural tenderizers in developing meat products is preferred (Mohd Azmi *et al*., 2023). In addition, these compounds are present in agroindustrial wastes; thus, their direct application through suitable technological processing or the extraction of bioactive ingredients could further improve the sustainability and profitability of this sector by opening a new arena for income generation and waste disposal.

Green papaya fruit and its latex are rich in papain, a cysteine protease used for tenderizing meat and other proteins. The proteolytic activity of papain extracted from papaya peel was about 10 times lower than that in the latex (Islamand Molinar-Toribio, 2013). The industrial processing of papaya (*Carica papaya*) fruit leads to the generation of huge byproducts comprising seeds (8.5%) and peel/ rind (12%) of the total fruit (Esguerra *et al*., 2020). Papain, present in papaya, effectively breaks peptide bonds in proteins and connective tissues, consequently leading to a softer, juicier, and more acceptable product to consumers, while also reducing cooking time (Bekhit *et al*., 2014). Papain enzyme extracted from papaya leaves was observed to damage collagen fibres, making their arrangement irregular and increasing the distance between muscle fibres in beef and goat meat (Kartika *et al.,* 2019). Incorporating these powders in place of pure enzymes would provide additional benefits, such as enhancing dietary fibre, mineral content, and antioxidant properties, while also alleviating the problem of solid waste disposal in the fruit industry.

The papaya rind could be used to improve the tenderness, nutritional value, and acceptability of goat meat. Therefore, the present study evaluated the effect of papaya rind paste on the quality characteristics of restructured goat meat nuggets.

MATERIALS AND METHODS

Preparation of Papaya Rind Powder

The fresh papaya rind was collected from the local fruit shops and brought to the laboratory. These are cleaned and washed with potable water and ground into a paste form by a mixer grinder for 8 minutes. The papaya rind paste was dried in a vacuum oven (NSW, New Delhi, India) at 60ºC for 24 h and ground to fine powder. The powder was packaged in polyethylene terephthalate (PET) jars and stored at ambient temperature till use.

Preparation of Restructured goat meat blocks (RGMB)

Goat meat was obtained from male goats scientifically slaughtered at the experimental slaughterhouse of the department by following standard protocols. The carcasses were aged overnight and manually deboned and trimmed to remove visible fat, fascia, and connective tissue followed by storing at −18 °C in low-density polyethylene (LDPE) bags. Prior to product preparations, the frozen meat was thawed under refrigeration at 4 ± 1 °C and manually cut into uniform cubes of approximately 1–1.5 cm. Various ingredients, as detailed in Table 1, were added to the goat meat cubes, thoroughly mixed, and conditioned under refrigeration for 5 hours. Based on the levels of papaya rind powder incorporation, four product batches were prepared: Control (without PRP), T1 (1% PRP), T2 (2% PRP), and T3 (3% PRP). The mixtures were transferred to a vacuum tumbler (Promarks Vac. Co. Ltd, Taiwan) and tumbled under vacuum for 3.5 hours until tacky exudates were formed (Fig. 1). The resulting goat meat batter was filled into aluminium molds (7.5 cm × 7.5 cm × 6.0 cm) and cooked in an autoclave at 15 psi for 15 minutes.

Following cooking, the molds were cooledto room temperature and then chilled overnight at 4 ± 1 °C. The chilled products were sliced to 8 mm thickness using a mechanical slicer (Sirman, Model Auto M 300 VV, Italy). The prepared goat meat blocks were subsequently analyzed for physico-chemical, proximate, and sensory attributes.

Goat meat

↓

Cut into 2.5cm cubes

↓

Add papaya rind powder (0%,1%,2%,3%), jamun seed powder (3%), Salt (1.7%),STPP (0.3%), Sodium Nitrate (120 ppm), spices (2%), and condiments (5%)

↓

Mix thoroughly

↓

Marinating under refrigeration for 2 h

↓

Vacuum tumbling for 2.5 h

↓

Put it into moulds (7.5x7.5x6cm^3) and steam cooking (15 min for15 psi)

↓

Analysis of cooked products

Fig. 1: Flow chart of preparation of restructured goat meat blocks

Table 1: Formulation for the preparation of functional restructured goat meat blocks incorporated with papaya rind paste

Ingredients	Control	T1	T2	T3
Goat meat	78	77	76	75
Water	10.0	10.0	10.0	10.0
Condiments	5.0	5.0	5.0	5.0
Spices	2.0	2.0	2.0	2.0
Salt	1.65	1.65	1.65	1.65
STPP	0.25	0.25	0.25	0.25
Sodium nitrite	0.10	0.10	0.10	0.10
Jamun seed powder	3.0	3.0	3.0	3.0
Papaya rind powder	—	1.0	2.0	3.0

PRP- Papaya rind powder, Control- product without PRP, T1- product with 1% PRP, T2- product with 2% PRP, and T3- product with 3% PRP, STPP- Sodium tetrapolyphosphate.

Proximate analysis

Moisture content of the developed blocks was estimated by oven drying, fat content by the Soxhlet extraction method, crude fibre using a Fibra Plus apparatus, protein content through the Kjeldahl distillation method (N × 6.25) and ash content by incineration in a muffle furnace by following the standard procedures described by the Association of Official Analytical Chemists (AOAC, 2000).

Cooking yield

Cooking yield was calculated to determine the extent of weight retention of the product after cooking. The weight of each sample was recorded before and after the cooking process. The difference in weight was used to assess the amount of moisture and fat loss during cooking. Cooking yield was expressed as a percentage and calculated using the following formula;

$$\text{Cooking yield (\%)} = [\text{Weight of raw batter / Weight of cooked product}] \times 100$$

pH estimation

The pH of restructured goat meat blocks was determined using a digital pH meter (Model: SAB 5000, LABINDIA, Mumbai, India) pre-calibrated with standard buffer solutions of pH 4.0, 7.0, and 9.0 prior to measurement.

Colour profile

The colour attributes of the developed blocks were determined using a chroma meter (Konica Minolta, Model CR-400; Illumination: D65, observer angle: 2°, aperture size: 8 mm). Prior to measurement, the instrument was calibrated with the standard white calibration plate provided by the manufacturer, following the recommended operating procedures. The colour profile was expressed in terms of L^* (lightness), a^* (redness), and b^* (yellowness) values.

Sensory evaluation

A panel comprising seven experienced in-house members evaluated the sensory attributes of the developed restructured goat meat blocks. Before serving, the product was heated in a microwave oven (LG Electronics India Pvt. Ltd., Mumbai) for 90 seconds. The samples were assessed for appearance, flavour, and tenderness using an 8-point descriptive scale, where higher scores indicated greater intensity or desirability of the attribute. Each sensory evaluation was performed in six replicates (n = 6). The collected data were statistically analyzed through Analysis of Variance (ANOVA), and mean comparisons were carried out using Duncan's Multiple Range Test (DMRT) as described by Snedecor and Cochran (1989). Statistical significance was determined at the 5% probability level ($p < 0.05$).

Statistical analysis

All experimental data generated in the present study were expressed as mean values accompanied by their respective standard errors (Mean ± SE). Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) software, version 26.0 (SPSS Inc., Chicago, IL, USA). The data were subjected to Analysis of Variance (ANOVA) to determine the existence of significant differences among the treatment means. Whenever a significant F-value was observed, Duncan's Multiple Range Test (DMRT) was employed as a post-hoc comparison test to identify the specific differences between treatments. Each parameter was evaluated in duplicate, and six independent observations (n = 6) were considered for statistical interpretation. The level of statistical significance was set at $p < 0.05$.

RESULTS AND DISCUSSION

Papaya rind powder

The proximate composition of papaya rind powder (PRP) depends upon the maturation stages, soil conditions, and cultivars. The PRP used in the present study had a pH of 4.72±0.13. The pH of the papaya rind depends on the variety and ripeness stage, with an increase in pH upon ripeness due to a decrease in acidity (Joshi and Dobhal, 2023). The acidic pH of the papaya rind is attributed to the presence of organic acids, including citric acid, ascorbic acid, and malic acid. Joshi and Dobhal (2023) reported the acidic nature of the papaya rind powder with a corresponding pH of 5.16.

The papaya rind is a good source of protein, fibre, and minerals. It is low in fat content. The moisture content of PRP was recorded at 8.58±0.57 %, and it contained 8.75±0.12% protein, 2.37±0.06% fat, and 20.75±1.53% fibre. It had a high content of minerals (7.69±0.75). Martial-Didier *et al*. (2017) noted the high nutritive value of the papaya rind with high content of crude fibre, minerals, protein, and fat. The authors also reported a high content of phosphorus and potassium. Werthera *et al*. (2000) also noted the low moisture content of papaya rind powder, with a moisture content ranging from 5% to 10%, thereby allowing for its storage for a more extended period without mold growth or spoilage. A higher mineral content (11%) in papaya rind powder was also reported by Santos *et al*. (2014) and 5.98% by Martial-Didier *et al*. (2017). Like the present study, Santos *et al*. (2014) also recorded the high dietary fibre content in the papaya rind powder (26% insoluble and 7% soluble fibre).

The physicochemical and proximate analysis of RGMB incorporated with PRP is presented in Table 2. The incorporation of PRP had a significant effect on the physicochemical parameters of RGMB. The cooking yield of the RGMB increased progressively with increasing levels of PRP, with T3 products yielding the highest cooking yield among all samples. The cooking yield followed the following trend: T3>T2>T1>C. The cooking yield of C and T1, as well as T1 and T2, was recorded as comparable. This improvement in cooking yield could be attributed to the higher fibre content in the treated products, thereby retaining the moisture and forming a firm gel. Similar findings of increasing cooking yield with increasing fibre content were observed in emu meat nuggets and chevon patties incorporated with finger millet flour by Chatli*et al*. (2015) and Kumar *et al*. (2015). The increased cooking yield in restructured spent hen meat slices was also recorded by Kantale *et al*. (2019) upon incorporating fig and pineapple peel powder. Azevedo and Campagnol (2014) also reported increasing **c**oking yield with the increase in the level of papaya seeds flour in beef burgers.

The pH of RGMB followed a decreasing trend with increasing levels of PRP (C > T1 > T2 >T3). The control sample had significantly ($p<0.05$) higher pH than the other treatments. This pattern could be attributed to the high acidity of the PRP used in the present study to replace the goat meat.

The moisture content of the control RGMB was recorded as significantly lower ($p < 0.05$) than T2 and T3, but was comparable ($p > 0.05$) to the T1 samples. The high dietary fibre content in the treated RGMB facilitated higher

Table 2: Effect of physicochemical and proximate of functional restructured goat meat blocks incorporated with papaya rind powder (Mean±SE)*

Parameters	C	T1	T2	T3
Cooking yield (%)	84.18±1.36^{a}	85.88±1.08^{ab}	86.96±1.32^{bc}	88.09±1.48^{c}
pH	6.38±0.05^{c}	6.26±0.03^{bc}	6.18±0.05^{ab}	6.09±0.08^{a}
Moisture (%)	66.85± 0.14^{a}	67.41 ± 0.47^{ab}	67.82 ± 0.21^{b}	68.34± 0.14^{c}
Protein (%)	17.86± 0.67	17.61± 0.52	17.42± 0.62	17.15± 0.19
Fat (%)	3.89 ± 0.09^{c}	3.72 ± 0.09^{bc}	3.65± 0.08^{b}	3.31 ± 0.08^{a}
Ash (%)	3.11 ± 0.12^{b}	3.03 ± 0.07^{ab}	2.96 ± 0.05^{a}	2.89 ± 0.07^{a}
Crude fibre(%)	1.52±0.05^{a}	2.35±0.01^{b}	2.88±0.08^{c}	3.25±0.06^{d}

* Means with different superscripts differ significantly (P<0.05) in a row; n = 6 for each treatment.

JSP- jamun seed powder, Control- product without papaya rind powder, T1- product with 1% papaya rind powder, T2- product with 2% papaya rind powder, and T3- product with 3% papaya rind powder.

moisture retention in the developed product. Similar findings were observed with increasing cooking yield when incorporating various plant powders such as broccoli powder in emu meat nuggets (Kumar *et al*., 2013), giloy powder in spent hen meat patties (Kumar *et al*., 2021), and sapota powder in pork patties (Kumar *et al*., 2018). The protein and fat content of RGMB decreased with progressively higher levels of PRP; however, for protein content, the values did not show statistically significant differences (p >0.05). The lowest fat content was recorded in T3 samples. The mineral content of the RGMB decreased with the incorporation of PRP. This decrease in protein, fat, and mineral content could be attributed to the replacement of goat meat with PRP in the formulations. The PRP incorporation had significantly increased (p < 0.05) the fibre content in the treated products, with a corresponding increase in crude fibre content as the levels of PRP incorporation increased. PRP is a rich source of fibre content, and its incorporation by replacing goat meat resulted in marked improvement in the crude fibre content of the developed products. Ahmed and Abdel-Rahman (2022) also reported a significantly higher fibre content in beef burgers by incorporating papaya wastes. Similarly, Evanuarini *et al*. (2025) also reported alterations in the physicochemical and proximate parameters of beef sausage added with papaya peel flour.

Colour profile

The colour plays a crucial role in determining the acceptability and marketability of the product. The colour variables of the RGMB with the incorporation of PRP are presented in Table 3. The incorporation of PRP decreased the lightness of the RGMB. The lightness value of the T3 samples was recorded as the lowest. The C and T1 lightness values were recorded as comparable. The yellowness (b*) value significantly decreased (p < 0.05) with increasing levels of PRP addition. The redness (a*) value increased upon PRP incorporation, with the highest redness being recorded for the T2 samples, which was significantly higher than that of the Control samples. Furthermore, T2 samples had substantially higher chroma than those of T3 samples. T3 samples had the highest hue, with hue values for C and T1 comparable. The decrease in lightness and redness values, and increased yellowness, could be attributed to the powder's innate yellow colour due to the presence of beta-carotene (Ovando-Martinez *et al*., 2018). The presence of a high amount of sugar could lead to a high Maillard reaction, leading to dark brown colour, leading to decreased L* and a* values. Ahmed and Abdel-Rahman (2022) also reported lowering lightness and redness values and increased yellowness values upon incorporating papaya waste in the beef burgers. Furthermore, the higher carotenoid content in PRP could also result in higher absorption of visible light; consequently, lowering the L* value in the beef burger was also reported by Velasco-Arango *et al*. (2020). Similar decrease in L* and a* values and a higher b* value were also recorded by the incorporation of finger millet flour in chevon patties Kumar *et al*., 2015). The increased hue value with the increasing PRP incorporation could indicate the higher orange colour of the product (Ovando-Martinez *et al*., 2018).

Texture profile

The hardness of RGMB decreased with the increasing levels of PRP incorporation. The hardness of the T3 samples was recorded as the lowest (Table 3). All treated samples exhibited a comparable hardness score. This hardness reduction upon adding PRP could be attributed to the better moisture retention of the treated products. Furthermore, the decrease in the hardness could also be due to the tenderising effect of the papain enzyme present in PRP. Similar findings were also reported by chevon meat patties upon incorporation of finger millet flour (Kumar *et al*., 2015) and giloy in spent hen meat patties (Kumar *et al*., 2021). The springiness values of C and T1 were recorded as comparable, similar to those of T2 and T3 samples. The PRP addition also increased cohesiveness, which might be attributed to the higher proteolytic activity and tenderising effect. However, the gumminess and resilience did not exhibit a significant difference (p>0.05).

Sensory evaluation

The sensory attributes of RGMB incorporated with varying levels of PRP are presented in Table 3. The appearance and colour scores of RGMB showed a decreasing trend with increasing levels of PRP incorporation; however, the differences were not statistically significant (p>0.05). This slight reduction in visual appeal could be attributed to increased darkening and a decline in lightness (L*) values, possibly due to the natural pigments and polyphenolic compounds present in the papaya rind powder. The flavour scores of RGMB improved significantly (p<0.05) with the inclusion of PRP up to the 2% level (T2). A higher addition above this, a marked decline was observed, as panelists reported an undesirable, dominant PRP flavour

Table 3: Sensory and textural attributes of functional restructured goat meat slices incorporated with papaya rind powder (Mean±SE)*

Parameters	C	T1	T2	T3
Colour profile				
L*	27.35±1.16^{ab}	27.99±1.08^{b}	26.61±1.52^{a}	23.66±1.10^{a}
a*	7.81±0.24^{d}	7.05±0.23^{c}	6.57±0.18^{b}	5.48±0.48^{a}
b*	8.54±0.61^{a}	9.15±0.51^{ab}	9.32±0.28^{b}	9.08±0.15^{ab}
Chroma	11.89±0.35^{c}	11.62±0.21^{bc}	11.41±0.11^{b}	10.68±0.09^{a}
Hue	53.18±0.75^{ab}	52.38±0.21^{a}	54.95±0.85^{c}	58.88±0.64^{d}
Texture profile				
Hardness (N)	19.73±1.27^{a}	18.84±0.81^{b}	18.67±1.27^{ab}	17.57±1.31^{ab}
Springiness (mm)	8.22±0.24^{a}	8.45±0.18^{a}	16.48±0.46^{b}	15.15±0.24^{b}
Cohesiveness	0.47±0.02	0.49±0.02	0.51±0.01	0.54±0.02
Chewiness (J)	294.76±0.81^{d}	197.28±0.88^{c}	176.35±1.64^{b}	164.27±1.09^{a}
Gumminess (N)	9.27±0.03	9.29±0.25	9.33±0.14	9.31±0.33
Resilience	1.69±0.13	1.72±0.48	1.71±0.02	1.73±0.08
Sensory attribute				
Appearance and colour	7.17±0.03	7.13±0.05	7.14±0.04	7.11±0.04
Flavour	7.09±0.09^{b}	7.26±0.03^{bc}	7.34±0.07^{c}	6.98±0.08^{a}
Juiciness	7.10±0.12^{b}	7.22±0.07^{bc}	7.26±0.11^{c}	6.68±0.10^{a}
Tenderness	7.02±0.08^{b}	7.15±0.05^{c}	7.35±0.11^{d}	6.51±0.10^{a}
Overall acceptability	7.11±0.04^{b}	7.25±0.12^{bc}	7.30±0.07^{c}	6.95±0.09^{a}

* Means with different superscripts differ significantly (P<0.05) in a row; n = 6 for each treatment.

JSP- jamun seed powder, Control- product without papaya rind powder, T1- product with 1% papaya rind powder, T2- product with 2% papaya rind powder, and T3- product with 3% papaya rind powder.

in T3 samples. The decrease in flavour acceptability at 3% PRP might also be linked to the bitter taste dur to inherent compounds in PRP.

Similarly, the juiciness and tenderness of RGMB exhibited an increasing trend up to 2% PRP incorporation. The papain enzyme naturally present in PRP likely contributed to the partial hydrolysis of muscle proteins, thereby improving tenderness and succulence. However, at the 3% level (T3), both attributes declined significantly ($p<0.05$). Panellists described these samples as excessively soft and rubbery, suggesting over-tenderization due to excessive proteolytic activity of papain. In terms of overall acceptability, the T2 samples (2% PRP) were rated the highest among all treatments, reflecting a balanced improvement in sensory qualities without adverse effects on flavour or texture. Conversely, the T3 samples received the lowest scores, primarily due to their off-flavour and undesirable mouth-feel. The overall acceptability of the T1 and T2 samples was found to be comparable, indicating that moderate incorporation of PRP (up to 2%) can improve the sensory attributes of restructured goat meat slices.

CONCLUSION

Based on the findings of the present study, high-quality functional restructured goat meat blocks can be developed by incorporating 3% jamun seed powder and 2% papaya rind powder. The optimized formulation exhibited enhanced nutritional value along with improved sensory characteristics.

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