RESEARCH ARTICLE Asian Journal of Dairy and Food Research, Volume 45 Issue 1: 85-93 (February 2026)

Effect of Alfalfa Seed Gum on the Rheological, Cooking and Textural Properties of Gluten-free Foxtail Millet and Chickpea Flour Noodles

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10.18805/ajdfr.DR-2406

ABSTRACT

Background: The research examined the feasibility of alfalfa seed gum (ASG), a new galactomannan hydrocolloid, as a functional ingredient in gluten-free noodles made from foxtail millet and chickpea flour (FCF). The aim was to enhance the dough functionality, cooking performance and sensory quality to produce a healthy alternative to wheat-based noodles.

Methods: To prepare noodles, ASG was added to the FCF blend at 1%, 2% and 3% levels. The samples were tested for rheology, cooking quality, texture, color and sensory properties. Rheology characterized the viscoelastic behavior and cooking tests characterized water uptake, cooking loss and matrix stability. Texture and color were instrumentally characterized and sensory analysis of overall acceptability was performed.

Result: Adding ASG improved the viscoelasticity of dough, cooking quality and texture properties, with the most pronounced effects observed at the 3% level. It was noted that noodles produced with ASG were slightly darker; however, in terms of sensory evaluation, noodles containing 3% ASG were the most preferred and exhibited similar characteristics to refined wheat noodles. Overall, ASG is a beneficial option for improving the structure of gluten-free noodles and consumer acceptance.

Key words: Alfalfa seed gum, Dough rheology, Gluten-free noodles, Tensile strength.

INTRODUCTION

Noodles are a traditional staple food with a history of use for thousands of years. Although the worldwide popularity of noodles is increasing due to their convenience, low cost and availability of various products with desirable sensory characteristics, including diverse tastes and textures, beneficial nutritional values and long shelf lives, noodles are still considered one of the primary carbohydrate-based foods, usually made from wheat flour. Wheat, a staple food globally and in India, is widely used for noodle production, but its gluten can trigger celiac disease, which is notably prevalent in northern India (Rafiq *et al*., 2016; Chauhan *et al*., 2017). High-protein flours, functional ingredients and gluten-free cereals (such as corn, millets, rice and buckwheat) are frequently used in the production of these products to enhance their nutritional properties (Dahal *et al*., 2021; Raungrusmee *et al*., 2020; Shukla *et al*., 2014; Fu *et al*., 2020).

Due to a growing interest in new food products and formulations, the food processing industry is turning toward alternative ingredients, with foxtail millet and chickpea flour emerging as excellent candidates for gluten-free products because of their nutritional composition. Foxtail millet (kangni) is a drought-tolerant crop and rich in nutrients, comprising approximately 60-70% carbohydrates, 8-12% protein, 2-4% fat, along with dietary fiber, essential vitamins and minerals (Divya *et al*., 2024). Similarly, chickpea flour (gram flour) is a highly nutritious ingredient, containing about 20-22% protein, 55-60% carbohydrates, 5-6% fat and 10-12% dietary fiber and also a valuable source of micronutrients such as iron, magnesium, phosphorus and B-vitamins (Kumari *et al*., 2024). Although the commercial potential of foxtail millet and chickpea flour has been well established, there is a lack of research on utilizing these flour sources to develop gluten-free noodles.

A key challenge in preparing gluten-free noodles is maintaining the textural properties inherently imparted by gluten; to mitigate this issue, hydrocolloids are frequently employed. Hydrocolloids, also known as gums, are high-molecular-weight biopolymers widely used in the food industry for their multifunctional roles in enhancing texture, stability and sensory quality. Most existing studies on gluten-free formulations have focused primarily on conventional hydrocolloids (xanthan, guar, pectin, psyllium and CMC), thus leaving a gap in research on potential alternative, novel, plant-based hydrocolloids. ASG, a sustainable and underused natural gelling agent with promising potential

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How to cite this article: Tomar, S., Yadav, B.S. and Yadav, R.B. (2026). Effect of Alfalfa Seed Gum on the Rheological, Cooking and Textural Properties of Gluten-free Foxtail Millet and Chickpea Flour Noodles. *Asian Journal of Dairy and Food Research*. **45(1):** 85-93. doi: 10.18805/ajdfr.DR-2406.

Submitted: 24-09-2025 **Accepted:** 13-11-2025 **Online:** 18-12-2025

to enhance texture, stability and elasticity in food systems, is also a driver of sustainability and scientific innovation (Shahzad *et al*., 2020; Srikaeo *et al*., 2020; Gasparre *et al*., 2019; Pan *et al*., 2016). Alfalfa is a perennial legume frequently cultivated as a forage crop, especially thriving in arid regions. The gum obtained from alfalfa seed is a non-conventional hydrocolloid, galactomannan in nature; it has a high molecular weight (4.02×10^6 g/mol) and good techno-functional properties; therefore, it can potentially be used as a substitute for conventional hydrocolloids in gluten-free noodles (Tomar *et al*., 2025; Hellebois *et al*., 2021). Implementing ASG in gluten-free formulations could increase dietary fiber and protein content, thereby improving digestive health and nutrient absorption and reducing the risk of gluten-related disorders. This approach could lead to the development of nutritious, functional, health-oriented and sustainable food products.

Therefore, this investigation sought to assess the effect of ASG on the rheological behavior, cooking quality and textural properties of noodles formulated from a blend of foxtail millet and chickpea flour.

MATERIALS AND METHODS

Alfalfa seeds were procured from M/S S.K. International, Gujarat (India). The extraction and purification of ASG were carried out using the methods prescribed by Tomar *et al*. (2025), with a yield and purity of 24.95% and 75.69%, respectively (Fig 1). The foxtail millet and chickpea flour were purchased from the local market of Rohtak, Haryana, India. The research was conducted in the Department of Food Technology, Maharshi Dayanand University, Rohtak, Haryana, India, from March 2024 to December 2024.

Chemical composition of flours

The moisture, ash, fat, protein and crude fiber content of the foxtail millet and chickpea flour samples were determined using standard methodologies (AOAC, 2000).

Noodle preparation

The noodles were prepared using the method reported by Hymavathi *et al*. (2019) with some modifications. A control sample was developed using 100% RWF and experimental noodles were prepared from a 70:30 composite of foxtail millet and chickpea flour blend, incorporating 1-3% ASG. The dough was made from 50 g of flour and distilled water. The ASG solutions were hydrated overnight at 4°C, stretched in a noodle machine (MARCATO), dried overnight at 45°C and then packed in polyethylene bags.

Rheological behaviour of dough

Oscillatory measurements

Dough rheology was assessed using a rheometer (MCR 102, Anton Paar, Germany) with a 25 mm plate and a 1 mm gap. After resting for 30 minutes at 25°C in sealed pouches, the dough was collected from the pouch, placed on a plate, trimmed and coated with oil to minimize moisture loss. Frequency sweep tests were performed from 0.1-100 rad/s at a constant strain of 1% and 25°C to assess storage modulus, loss modulus and tangent delta.

Creep and recovery behavior

Creep was measured using stress-relaxation tests at 25°C, where a constant stress of 70 Pa was applied for 150 s. Samples were allowed to recover for 300 s. Creep compliance was used to assess dough viscoelasticity and the data were fitted to the Burger model using the rheometer software.

$$\text{Creep phase } J(t) = J_o + J_m [1 - \exp(-t/\lambda)] + t/\eta o \quad ...(1)$$

$$\text{Recovery phase } J(t) = J_{max} - J_o - J_m [1 - \exp(-t/\lambda)] \quad ...(2)$$

Where,

J_{max}= Maximum creep compliance.

ηo= Zero-shear viscosity,

J_0 and J_m= Instantaneous compliance.

λ= Mean retardation time.

Cooking properties of noodles

The physicochemical cooking attributes of the noodles were meticulously evaluated according to the method detailed by Narwal *et al*. (2022). The optimal cooking time was determined by boiling 6 g of noodles in 100 mL of distilled water until the core of the noodles was fully cooked. The cooking loss was calculated by drying the cooking water at 105°C for 22 hr and expressed as a percentage. Water absorption was determined by measuring the difference in the weight of cooked and uncooked noodles after wiping off their surface moisture.

$$\text{Water absorption} = \frac{\text{Weight of cooked noodles} - \text{Weight of uncooked noodles}}{\text{Weight of uncooked noodles}} \times 100 \quad ...(3)$$

Color analysis

The chromatic characteristics of the noodle samples were evaluated using a HunterLab colorimeter (Colorflex EZ 45/0 model, U.S.A). Before measurement, the instrument was calibrated with a standard white plate and for each sample, triplicate color readings were acquired from distinct locations. The obtained data are expressed as L*, a* and b* values, representing the CIELAB tristimulus system.

Texture analysis

Cooked noodles were tested on a texture analyzer using a 35 mm pasta firmness probe and a 5 kg load cell. 70 mm noodle segments were measured at pre-, test- and post-test speeds of 1, 2 and 5 mm/s, respectively, with 80% strain and an 8 g trigger force to get hardness, cohesiveness, springiness, gumminess and chewiness. Tensile strength was measured in extension mode using an A/SPR probe, a 5 g trigger, speeds of 1-2 mm/s and a fixed hook separation of 100 mm.

Sensory analysis

The sensory analysis of noodles at varying concentrations of hydrocolloids was conducted by 25 semi-trained

panelists (10 females and 15 males), aged 22-25 years, using a 9-point hedonic scale. The samples were judged in terms of texture, aroma, flavor, color, mouthfeel and general acceptability, with judges rinsing their mouths with water between samples to prevent taste carryover.

Statistical analysis

All experimental measurements were performed in triplicate, with the results expressed as the mean±standard deviation. Statistical analysis was conducted using SPSS software, specifically a one-way ANOVA complemented by a Tukey's HSD post-hoc test ($p<0.05$) and PCA analysis was carried out using Minitab software.

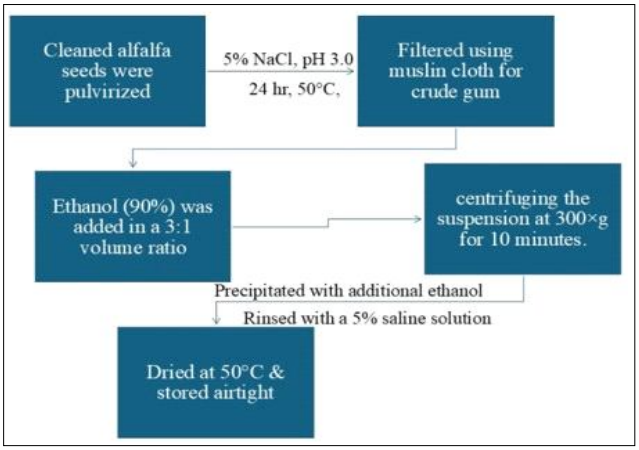


Fig 1: Flow chart of the extraction of ASG.

RESULTS AND DISCUSSION

Chemical composition of FCF

The proximate analysis of foxtail millet revealed moisture (7.95%), fat (3.45%), ash (2.65%), protein (10.75%) and crude fibre (3.33%). On the other hand, chickpea flour had 6.35% moisture, 4.96% fat, 18.94% protein, 9.19% crude fibre and 3.79±0.32% ash. The proximate standard values indicate that foxtail millet and chickpea flour have a comparable nutrient profile, making them effective ingredients for various food formulations that enhance nutritional quality.

Dough rheology

Frequency sweep analysis

The dynamic oscillatory rheological test was conducted to evaluate how ASG affected the viscoelastic characteristics of gluten-free dough made with FCF, with RWF as the control. The results of a dynamic rheological study indicated that all dough recipes behaved in a typical viscoelastic manner (G′>G″), indicating their characteristics as weak gels with both moduli increasing with frequency (Fig 2a). G′ and G″ were lowest for RWF control, while the dough with 3% ASG had the highest G′ and G″ values, suggesting a greater structural integrity of the dough and gel network strength. This structural enhancement may be due to tighter ASG interactions with the biological matrices of starch-protein that are formed from hydroxyl groups, which form hydrogen bonds between water and biopolymer and ultimately stabilize the dough matrix, thereby improving

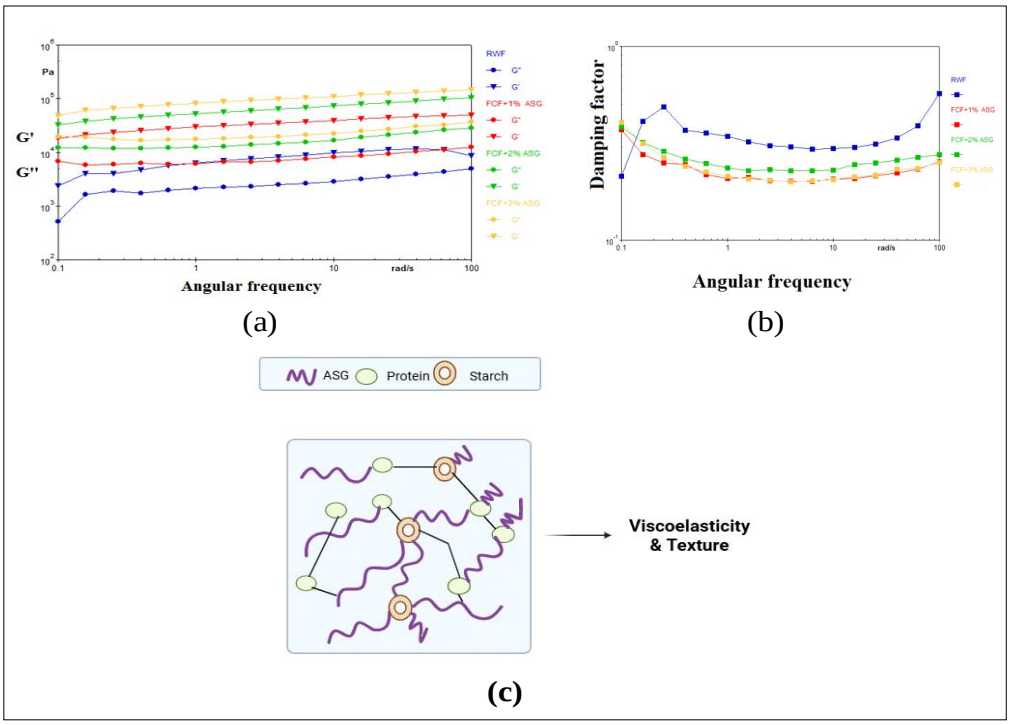


Fig 2: (a) Frequency spectra, (b) damping graph of foxtail millet-chickpea dough incorporated with ASG and (c) mechanism of ASG, starch and protein interaction.

structure (Lazaridou *et al*., 2007) (Fig 2c). In addition, the low tan ä values of ASG-enriched doughs confirmed them to have elastic behavior (Fig 2b), with 3% ASG forming the most rigid gel structure and indicating the effectiveness of ASG to improve the viscoelastic properties of gluten-free dough. Comparable observations have been previously documented concerning gluten-free formulations incorporating various hydrocolloids (Dangi *et al*., 2020).

The Power Law model was utilized to quantify the relationship between frequency and the dough systems. The control sample had the lowest a and b values, indicating a weaker structure, while the 3% ASG dough had the highest values, suggesting a stronger structure (Table 1). The reduction in frequency dependence as the amount of ASG increased, noted in frequency sweep tests, indicates increased stability and lower deformability, which suggests ASG addition improved the processing stability and texture of the dough (Liu *et al*., 2017).

Creep and recovery behavior

Creep and recovery tests were conducted to evaluate the viscoelastic properties of FCF doughs containing varying levels of ASG. The viscoelastic behavior was exhibited by all of the samples, with the RWF control demonstrating the highest Jo value and a reducing Jo value when ASG was added (1-3%), presenting a higher structural strength and resistance to deformation (Fig 3). The 1% ASG dough showed the lowest Jo, indicating a stiffening effect, while decreased J_1 and J_{max} values reflected reduced deformation. The progressive increase in λ_1 with higher ASG levels confirmed the formation of a more stable and resilient viscoelastic network (Table 2).

In the recovery phase, the dough with 3% ASG showed the lowest Jo and J1 values and the highest elastic recovery (58.53%), indicating the dough had greater bounce back and firmness. The extended retardation time for the dough with 3% ASG also contributed to elastic recovery, which suggested that the 3% ASG used in this study helps develop the matrix of the gluten-free dough by forming a stable and cohesive viscoelastic network, which supports previous research conducted with hydrocolloid-enriched systems (Dangi *et al*., 2020).

Cooking characteristics of FCF noodles incorporated with ASG

The addition of ASG has influenced the cooking characteristics of FCF noodles, as cooking time was the highest for RWF noodles because of the contribution of the gluten network; whereas 1% of ASG noodles had the least cooking time, presumably due to a weaker structure. However, an increase in ASG (2-3%) resulted in a corresponding increase in cooking time (from 10.70 to 12.29 min). From these results, it appears that ASG made a positive contribution to augmenting matrix strength and water retention, thereby extending the cooking time required for gelatinization of the starch (Table 3). This observation aligns with the findings of Tangthanantorn *et al*. (2021), who noted that hydrocolloids can enhance the strength of the structure through hydrogen bonding interactions with starch.

Table 1: Power law parameters for storage and loss modulus of foxtail millet-chickpea dough incorporated with ASG.

Samples	G′x	a (Pa.s)	R^2	G″(y)	b (Pa.s)	R^2
RWF	0.19	5597	0.98	0.21	1872	0.99
FCF+1% ASG	0.13	28329	0.99	0.10	6772	0.97
FCF+2% ASG	0.15	50993	0.99	0.12	13637	0.99
FCF+3% ASG	0.14	78744	0.98	0.09	1988	0.98

Where G′ and G″ are storage and loss modulus, “a” and “b” indicate the modulus size at a particular frequency.

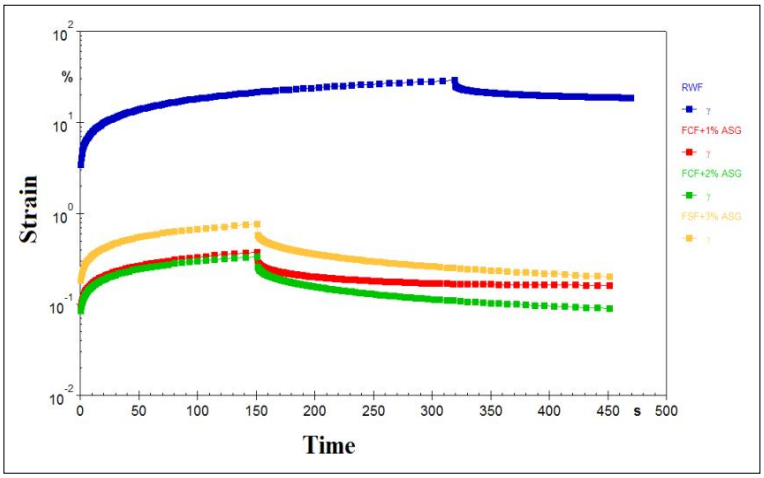


Fig 3: Creep-recovery behaviour of foxtail millet-chickpea dough incorporated with ASG.

The cooking loss, which reflects the loss of solid materials, was most significant at 1% ASG, where there was a weak structure, followed by a substantial reduction in cooking loss at 3% ASG due to strong starch-gum interactions and cohesive matrix (Table 3) (Dibakoane *et al*., 2025). The cooked weight was lowest at 1% ASG but increased to 14.79 g at 3% ASG, indicating improved water retention with higher gum levels, consistent with Gasparre *et al*. (2019). WAC followed the same trend, increasing from 1.34 g/g (1% ASG) to 1.69 g/g (3% ASG), indicating an enhanced hydration potential of ASG at higher concentrations. The expansion ratio, however, declined with increasing ASG concentration, suggesting a denser, less swellable structure (Detchewa *et al*., 2022).

Color analysis of cooked noodles

The control RWF noodles exhibited the highest lightness, whereas ASG-enriched noodles showed a pronounced darkening effect, with L* decreasing from 15.3 at 1% ASG to 20.0 at 3%. Simultaneously, the a* shifted from slightly green in RWF to distinctly redder tones in ASG samples and b* dropped sharply from 12.8 to values between 2.5 and 4.5 (Table 3). These changes reflect the inherent color compounds in ASG that suppress brightness while enhancing red hues and reducing yellow tones.

Texture analysis

The textural characteristics of FCF noodles were greatly influenced by the incorporation of ASG. The RWF control had the highest hardness attributed to its gluten network, while noodles with 1% ASG exhibited lower hardness, indicating a weaker structure. When the concentration of ASG was increased, the hardness increased to 1499 g at 3%, suggesting some reinforcement of the noodle structure due to gel formation and moisture interaction (Sutheeves *et al*., 2020). Similarly, springiness, cohesiveness, gumminess and chewiness all improved with the increased levels of ASG content, suggesting a greater level of internal bonding and viscoelasticity. The increased levels of resilience and extensibility are also enhanced, exhibiting greater elasticity and flexibility, which supports the positive influence of ASG on noodle texture (Table 4) (Padalino *et al*., 2016).

Tensile strength, indicating noodle resistance to stretching or breaking, improved notably with increasing ASG concentration. While the RWF control showed the highest strength due to gluten, gluten-free noodles with 3% ASG achieved 30.25 g, which is significantly higher than lower ASG levels. This enhancement reflects ASG's ability to form a cohesive and elastic matrix through gel formation and water binding, partially mimicking the structural role of gluten. Thus, 3% ASG effectively strengthened the noodle matrix, enhancing its mechanical integrity and flexibility (Dahal *et al*., 2021; Jiang *et al*., 2025).

Sensory analysis of cooked noodles

The sensory scores of RWF noodles and FCF noodles supplemented with different concentrations of ASG, evaluated for texture, flavour, colour, mouthfeel, aroma and overall acceptability (Fig 4a). RWF noodles received the highest sensory scores primarily as a result of gluten's contribution to texture and quality. Among the samples supplemented with ASG, 3% of the ASG noodles exhibited superior texture, mouthfeel and overall acceptability, similar to the RWF control. These results align with ASG's stated capabilities, with gel-forming attributes and water-binding abilities contributing to elasticity and cohesiveness. While the 1% ASG noodles lacked sensory appeal, higher levels of ASG, particularly the 3% ASG noodles, significantly enhanced the quality of gluten-free noodles (Fig 4b).

The instrumental texture results, which showed increased hardness, chewiness and extensibility in noodles with 3% ASG, aligned firmly with sensory panel evaluations of the texture and mouthfeel of this level of ASG. The structural integrity and elasticity achieved by ASG resulted in a firmer, more cohesive and more satisfying bite, which corresponded with sensory scores that corroborated this increase in functional quality. The precise alignment of texture and

Table 2: Creep parameters of foxtail-chickpea flour dough incorporated with ASG.

Test phase	Parameter	RWF	FCF+1% ASG	FCF+2% ASG	FCF+3% ASG
Creep	J_o (10^{-5}) (Pa^{-1})	7.11±0.13^a	0.46±0.06^b	0.53±0.03^b	0.60±0.01^b
	J_1 (10^{-5}) (Pa^{-1})	10.30±0.43^a	0.93±0.04^c	1.60±0.11^b	2.00±0.01^a
	λ_1 (s)	14.6±0.57^c	20.19±0.27^b	28.46± 0.66^a	37.15±0.81^a
	R^2	0.98	0.99	0.98	0.99
	J_{max} (10^{-4}) (Pa^{-1})	1.88±0.14^a	0.48±0.04^b	0.40±0.01^c	0.37±0.02^c
Recovery	J_o (10^{-5}) (Pa^{-1})	4.65±0.21^a	0.54±0.06^b	0.54±0.01^b	0.50 ±0.01^b
	J_1 (10^{-5}) (Pa^{-1})	6.10±0.15^a	0.84±0.01^c	0.89±0.01^b	0.95±0.03^b
	λ_1(s)	12.49±0.55^c	52.99±0.93^b	59.47± 0.77^a	66.90±0.15^a
	R^2	0.99	0.98	0.98	0.99
	% elastic	64.26±1.36^a	48.96±0.07^b	53.52±0.37^b	58.53±0.84^b
	% viscous	36.91±0.30^b	64.62±0.54^a	69.15±0.45^a	71.90±1.11^a

The results are reported as the mean±SD of three independent measurements.

Values in the duplicate rows with different superscripts indicate significant difference ($p<0.05$).

Where J_{max} represents maximum creep compliance, J_0 and J_1 are the instantaneous compliance and λ represents the mean retardation time.

Table 3: Cooking quality and color attributes of foxtail-chickpea noodles incorporated with ASG.

Sample	Cooking time (min)	Cooked weight (g)	Cooking loss (g/100 g)	WAC (g/g)	Expansion ratio	L*	a*	b*
RWF	11.38±0.54^{a}	13.98±0.06^{a}	10.27±0.38^{b}	1.79±0.06^{a}	0.88±0.04^{a}	85.88±0.79^{a}	-0.40±0.03^{c}	12.82±0.10^{a}
FCF+1% ASG	8.33±0.18^{c}	8.29±0.09^{c}	16.58±0.45^{a}	1.34±0.08^{c}	0.68±0.01^{b}	15.25±0.90^{d}	0.41±0.05^{b}	2.55±0.01^{d}
FCF+2% ASG	10.70±0.58^{b}	11.28±0.55^{b}	13.08±0.36^{ab}	1.48±0.03^{b}	0.65±0.02^{b}	17.34±0.47^{c}	1.66±0.46^{a}	3.00±0.01^{c}
FCF+3% ASG	12.29±0.51^{a}	14.79±0.32^{a}	8.35±0.18^{c}	1.69±0.10^{a}	0.59±0.01^{c}	20.04±0.07^{b}	2.83±0.25^{a}	4.50±0.04^{b}

The results are reported as the mean±SD of three independent measurements.

Values in the same rows with different superscripts indicate a significant difference ($p<0.05$).

Table 4: Texture profile of foxtail-chickpea noodles incorporated with ASG.

Sample	Hardness (g)	Springiness (mm)	Cohesiveness	Gumminess (g)	Chewiness	Resilience	Extensibility (mm)	Tensile strength (g)
RWF	4664.5±3.5^{a}	0.88±0.04^{a}	0.61±0.01^{a}	2774.02±8.46^{a}	2529.14±48.9^{a}	0.48±0.11^{a}	31.79±0.69^{c}	26.08±0.96^{b}
FCF+1% ASG	1257.0±26.9^{d}	0.51±0.03^{c}	0.38±0.01^{c}	522.74±8.89^{c}	499.52±14.86^{c}	0.27±0.03^{c}	36.96±1.82^{b}	19.95±0.09^{c}
FCF+2% ASG	1337.0±2.8^{c}	0.60±0.01^{b}	0.46±0.04^{b}	544.71±8.12^{b}	532.42±2.11^{b}	0.33±0.03^{b}	45.67±3.26^{b}	24.52±1.62^{b}
FCF+3% ASG	1499.5±2.1^{b}	0.70±0.02^{a}	0.57±0.02^{a}	596.05±7.16^{b}	563.00±3.00^{b}	0.45±0.04^{a}	58.44±2.28^{a}	30.25±1.34^{a}

The results are reported as the mean±SD of three independent measurements.

Values in the same rows with different superscripts indicate significant difference ($p<0.05$).

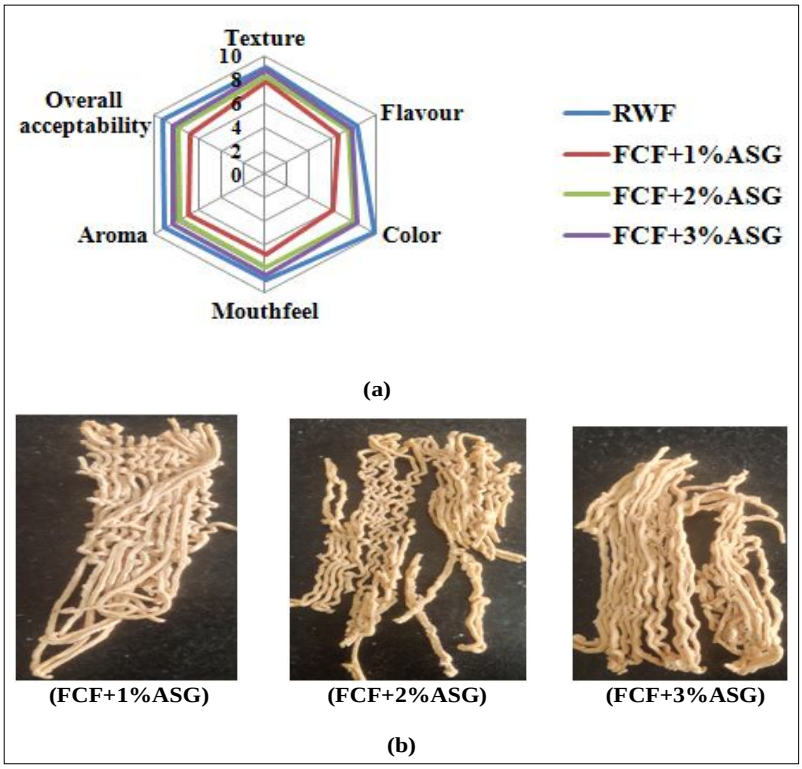


Fig 4: (a) Sensory attributes and (b) images of foxtail-chickpea noodles incorporated with ASG.

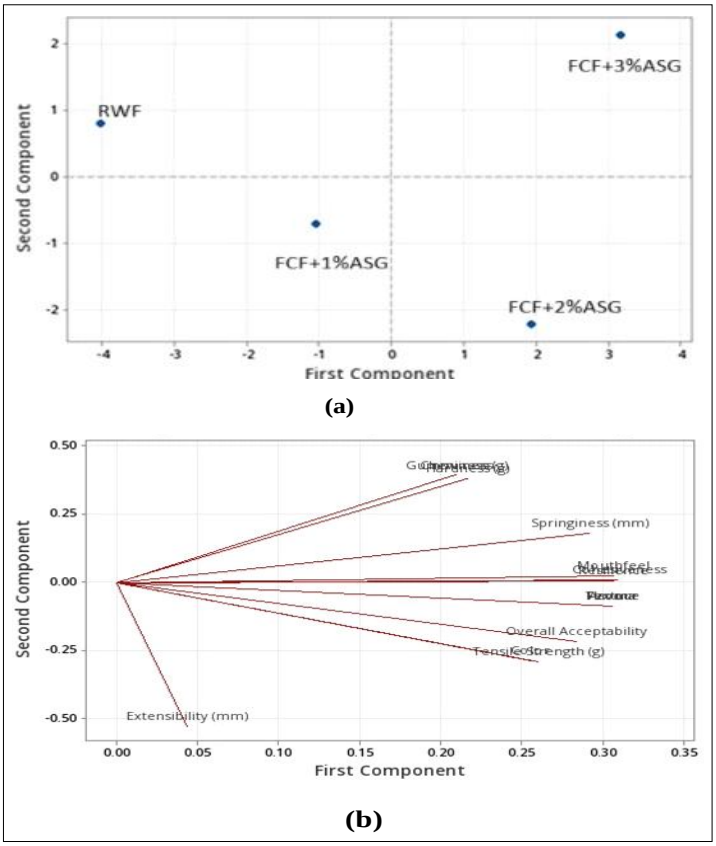


Fig 5: PCA (a) score plot and (b) loading plot of sensory and textural instrumental data.

sensory data underscores ASG's potential to enhance both the functional and consumer-perceived quality of gluten-free noodles, as evidenced by the 3% ASG treatment, which showed the most significant improvement in terms of texture, acceptability and nutritional quality.

PCA sensory and textural data analysis

The PCA score and loading plots enabled clear differentiation of the noodle samples based on their textural and sensory attributes (Fig 5a, b). Hardness, gumminess, chewiness and tensile strength were the primary characteristics of PC1 (57.4%), whereas cohesiveness, resilience and springiness were the primary characteristics of PC2 (27.8%), which together accounted for 85.2% of the variability. While samples on the negative side of PC1 demonstrated higher extensibility and sensory acceptability, those on the positive side demonstrated greater firmness and structural integrity. Although hardness and gumminess showed an inverse relationship, indicating that excessive firmness decreases consumer preference, the loading plot showed a positive correlation between tensile strength, texture, flavor and overall acceptability. Overall, PCA demonstrated how strongly textural and sensory characteristics interact to affect the acceptability and quality of noodles.

CONCLUSION

Incorporating ASG into FCF noodles significantly enhanced the dough's viscoelastic behavior. They improved the gluten-free product's cooking, texture and sensory attributes. Among the tested concentrations, 3% ASG demonstrated the most favorable results in terms of rheological stability, reduced cooking loss, higher tensile strength and overall sensory appeal. These improvements are attributed to the gel-forming and water-binding capabilities of ASG, which compensated for the absence of gluten. Thus, ASG is an effective natural hydrocolloid used in gluten-free formulations to improve quality without compromising nutrition or consumer acceptability. ASG reveals potential applications in gluten-free instant noodles and other functional food from both industrial and consumer perspectives, as an innovative, health-oriented and sustainable option in the modern food marketplace. Although 3% ASG demonstrated the best results, higher concentrations were not examined and should be investigated in future studies to assess the maximum functional potential of ASG in gluten-free formulations.

ACKNOWLEDGEMENT

The authors acknowledge the University Research Fellowship granted by Maharshi Dayanand University, Rohtak (India).

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Conflict of interest

The authors declare that they have no conflict of interest.

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