



# Rheological and Textural Characterisation of Chickpea Dough and Baked 3D-Printed Snacks Enriched with *Alphitobius diaperinus* and *Locusta migratoria* Powders

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## Abstract

Edible insect powder is a new ingredient that can be used to create innovative functional and nutritional properties in food products. However, adding insect powder to bakery goods could impact the dough's technological and sensory attributes. This study aims to investigate possible alterations in dough enriched with insect powder and examine the texture of salty snacks produced using a 3D food printer. The doughs were prepared using varying quantities of two types of edible insect powders. The stiff flow properties showed a pseudoplastic behaviour that fit well with a power-law equation. Viscosity and pseudoplasticity increased in proportion to insect powder concentration, with the strongest effect observed for *L. migratoria*. The linear viscoelastic behaviour exhibited  $G'$  values exceeding  $G''$  values, and both moduli increased with insect concentration. *A. migratoria* displayed a greater elastic contribution (lower  $\tan \delta$ ) compared to *A. diaperinus*, which correlates with the lower printability of *A. migratoria*. The texture of the snacks prepared with *A. diaperinus* demonstrated a rise in the breaking force as the insect concentration increased and exhibited a corresponding texture profile to the control and the 4.6% sample. Moreover, the addition of *A. diaperinus* heightened the crispiness.

**Keywords** Insect powders · 3D printing · Rheological properties · Textural properties · Salty snack

## Introduction

The Food and Agriculture Organization (FAO) of the United Nations reports that, based on estimates, the current global population of 7 billion is expected to increase to 9.85 billion by 2050 (Van Huis et al., 2013). Therefore, food demand is predicted to increase dramatically amid already strained

agricultural land. Therefore, finding alternative protein and fat sources for feed and food can alleviate pressure on over-used sources, including livestock. In recent times, insects have emerged as a viable alternative to conventional sources of fat and protein owing to their nutritional value and sustainable nature (Hall et al., 2017). Consumable insects, rich in fats, proteins, and micronutrients, are an excellent nutrition source and can be used as a highly nutritious ingredient (Rumpold & Schülter, 2013). Various insect powders have been used, for example, to fortify bakery products (Khatun et al., 2021) or to improve the nutritional quality of extruded snacks (Gomes et al., 2023). Several studies have shown a negative linear correlation between the quantity of insect powder (*Acheta domesticus*, *Nauphoeta cinerea*) and the technological parameters (Kathun et al., 2021; Osimani et al., 2018; de Oliveira et al., 2017).

3D food printing is a developing technology for direct manufacturing that involves the layer-by-layer deposition of materials to produce a 3D structure (Sundarsingh, et al., 2023; Seung Yun Lee et al., 2023). In this process, the rheological characteristics of the printed materials influence

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the outcomes of the printing. The properties of food that affect viscosity, consistency, and elasticity play a crucial role in 3D printing to achieve the desired structure (Dankar et al., 2018; Kim et al., 2018; Liu et al., 2017; Nachal et al., 2019). Specifically, the viscosity of the food should be low enough to ensure smooth extrusion through the 3D printer, but then increase immediately after the extrusion process to maintain the printed product's shape. Additives are commonly used in 3D printing to improve the printing properties of food (Azam et al., 2018; Guo et al., 2019). Incorporating olive oil into the dough for printing renders it smoother and more liquid due to the plasticising and lubricating effect of the fat in the ingredients (Liu et al., 2019). Similar observations have been made with the use of egg yolk, which facilitates the printing of the dough. Chen et al. (2019) demonstrated that the printing ability of soybean protein isolate is improved through the incorporation of xanthan gum, which is related to its shear-thinning characteristics. The viscosity of the starch printing system is increased by adding guar gum, improving its stability during heating and stirring. In this sense, Cai et al. (2023) explained the importance of food hydrocolloids in 3D printing of purple sweet potato puree and their effect on physical properties, microstructure, and printing performance. They concluded that of all the hydrocolloids studied, guar gum had significantly the highest print stability. Several studies have been attempting to combine insect powders of their extracts with 3D printing technology. Soares and Forkes (2014) studied the possibility of using 3D dimensionally extruded insect paste filament as a method of creating foodstuffs and Severini et al. (2018) studied 3D printing technology to produce snacks formulated with wheat flour enriched with ground yellow mealworm larvae.

In summary, there are studies where insects are used as an alternative source of protein for the development of new products and studies where 3D printing technology is used for food development, where the importance of the rheological properties of the food to achieve a suitable texture is highlighted. As far as we know, no previous research has investigated the rheological and textural properties of insect-enriched snacks made with 3D printing technology. The objective of the present work was to examine the rheological impacts of enriching chickpea dough with diverse concentrations of *Alphitobius diaperinus* and *Locusta migratoria* powders and to investigate the textural behaviour of adding *A. diaperinus* into 3D-printed snacks.

## Materials and Methods

### Dough Preparation

The dough ingredients were chickpea flour (46.3%, La Finestra Sul Cielo S.A., Madrid, Spain), water (39.4%), extra

virgin olive oil (11.6%, Hacienda Ortigosa S.L., Navarra, Spain), curry powder (1.8%, Westmill Foods, London, UK), and salt (0.9%, Sal Costa, S.L.U., Barcelona, Spain) (García et al., 2021). Different amounts of *A. diaperinus* or *L. migratoria* (Kreca Ento-Food BV, Ermelo, The Netherlands) were added ranging from 0% (control) to 13.9% (enriched samples), replacing part of the chickpea flour fraction (0, 4.6%, 9.3%, and 13.9%). All ingredients were weighed (50.0 g of total dough mass) and mixed with a hand blender (Bluesky BHB170-16) for 2 min. The particle size of milled insect powder was 310  $\mu\text{m}$  (span 2.2), 967  $\mu\text{m}$  (span 1.1), and for *A. diaperinus* and *L. migratoria*, respectively.

### 3D Printing and Baking Process

A Focus 3D Food Printer (byFlow, Eindhoven, Netherlands) was used to print the doughs following the process used by García-Gutiérrez et al. (2021). A 1.6 mm nozzle was used at a speed of 30 mm/s and each formulation was made in triplicate. The 3D-printed snacks were baked at 180 °C for 12 min using the ventilation mode of a vapour oven (3HV469X/02 model, Balay, Pamplona, Spain). Nutritional composition of doughs and *A. diaperinus* 3D-printed snacks is shown in supplementary Tables S1 and S2, respectively.

### Rheological Measurements

Rheological measurements were made with a controlled stress rheometer (AR-G2, TA Instruments, Crawley, England) equipped with a Peltier heating system set at 20 °C. A 40 mm diameter plate-plate geometry with a serrated surface and a gap of 1 mm was used. The samples equilibrated for 10 min between plates prior to measurements. Silicon oil was applied to the sample's outer edges to prevent drying.

### Flow Properties

Flow-stepped tests were conducted over a log distribution from 0.5 to 50  $\text{s}^{-1}$ , with 10 data points per decade and 10 s of equilibration time.

### Linear Viscoelastic Measurements

Stress sweeps ranging from 0.01 to 200 Pa were conducted to ascertain the linear viscoelastic region. Both  $G'$  and  $G''$  were monitored during the application of shear stress. When within the linear viscoelastic region,  $G'$  and  $G''$  remain unaffected by the applied stress or strain. A series of frequency sweeps (10 to 0.01 Hz) were then performed in this linear viscoelastic region at a stress wave amplitude that was well within acceptable limits. The stress wave amplitude has been set at 0.6 Pa in the doughs that did not contain insect powder. However, it was increased to 1 Pa in the doughs with 4.6%,

9.3%, and 13.9% insect powder concentrations. The values of  $G'$ ,  $G''$  and the loss tangent =  $G''/G'$  were recorded.

### Texture Profile Analysis

Texture measurements (breaking strength and penetration tests) were performed with a TA-XT.plus Texture Analyser equipped with Texture Exponent software (version 2.0.7.0.; Stable Microsystems, Godalming, UK). The tests were conducted at room temperature ( $20 \pm 1$  °C) 24 h after preparation. Three 3D-printed snacks per formulation were used for measurement to ensure reproducibility, and two repetitions of each sample were evaluated on different days.

#### Breaking Strength Three-Point Bending Test

Snacks were broken with the three-point bending probe (A/3 PB) (Fig. 1a). The experimental conditions support 70 mm apart, a 10-mm probe travel distance, a trigger force of 0.05 N, and a test speed of 1 mm/s. The breaking force (N) was measured.

#### Penetration Test

The penetration test was conducted with the upper Volodkevich Bite Jaw (VB) (Fig. 1b), penetrating the snack to 1.5 mm at a test speed of 1 mm/s and a trigger force of 0.05 N. The area under the penetration curve (N.s), which is related to hardness, and the number of force peaks as an index of crispness, were also measured.

### Statistical Analysis

The raw data obtained were statistically analysed using a one-way analysis of variance (ANOVA) to evaluate the

effects of the different percentages of insect powders on the rheological and textural properties of dough and snacks. To analyse the significant differences between the different samples, Fisher's test was used (significance at  $p < 0.05$ ). Statistical analyses were performed using the XLSTAT software (2019.2.2, Addinsoft, Barcelona, Spain).

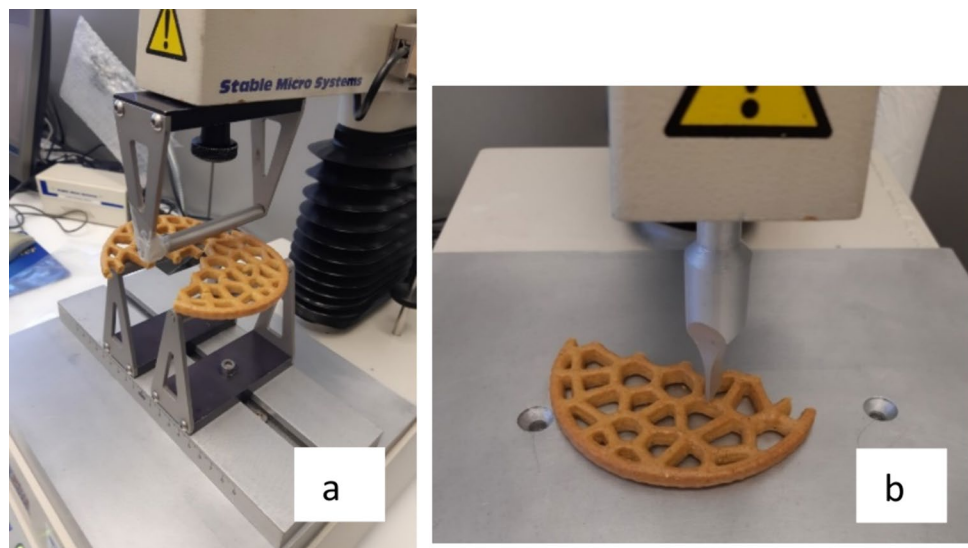
## Results and Discussion

### Flow Curves

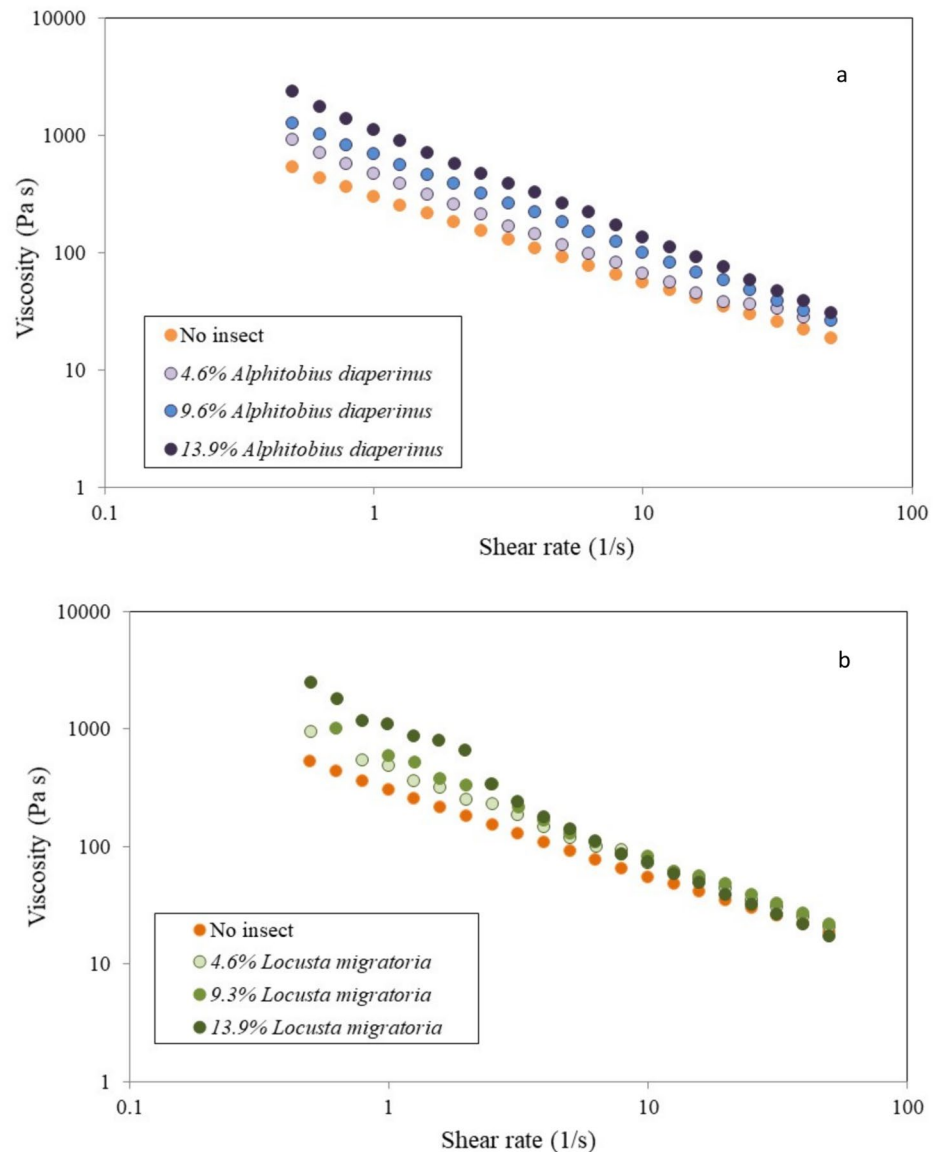
Because 3D printing technology is related to the flow of the material, it is considered important to study the rheological properties of the products to be printed (Qiu et al., 2022). For proper 3D printing, the viscosity of the food must be low enough to be extruded through a small nozzle but high enough to form proper layers when printing without causing deformation of the food (Godoi, Prakash, and Bhandari, 2016). Therefore, the flow properties of food materials should be shear thinning (Gholamipour-Shirazi et al., 2020; Liu & Zhang, 2019; Prakash et al., 2019; Sun et al., 2020).

The effect of adding *A. diaperinus* and *L. migratoria* powders to the flow properties is shown in Fig. 2. A decrease in viscosity was detected when an increase in the shear rate was applied, showing a pseudoplastic behaviour for all the doughs tested. The increase in the amount of insect powder added to the chickpea dough also produced an increase in their viscosity in all the shear rate ranges studied ( $0.5$  to  $50$  s<sup>-1</sup>). Furthermore, the differences were more evident at lower shear rates due to the higher pseudoplasticity behaviour found when adding a higher amount of insect powder (13.9%). The existing differences at lower shear rates became smaller at higher shear rates due to the pseudoplastic behaviour and to a higher

**Fig. 1** Texture tests applied. **a** Bending test. **b** Penetration test



**Fig. 2** Flow curves of chickpea dough enriched with edible. **a** *Alphitobius diaperinus*. **b** *Locusta migratoria* powders



degree of pseudoplasticity at higher amount of insect powder. Higher pseudoplasticity implies higher slope of the log/log viscosity versus shear rate curve, so the differences found at lower shear rate become lower at higher shear rate.

To better understand the differences between samples, the viscosity versus shear rate data were well adjusted to a power-law Eq. (1):

$$\eta = \eta_1 \dot{\gamma}^{n-1} \quad (1)$$

where  $\eta_1$  is the viscosity at  $1 \text{ s}^{-1}$  and  $n$  is the power-law index, which represents the degree of pseudoplasticity of the sample. The parameter  $n$  is related to the slope of the viscosity versus shear rate curve. Values of  $n=1$  represent Newtonian behaviour (viscosity does not depend on the shear rate). The higher the difference of  $n$  from 1, the higher the pseudoplasticity (Schramm, 2004). Lower  $n$  values represent

a higher decrease of viscosity with the increase in shear rate, implying higher pseudoplasticity and an increase in structural complexity, which is favourable in the context of their application for 3D printing. The mean values of  $\eta_1$  and  $n$  are presented in Table 1.

**Table 1** Flow parameters of the dough samples

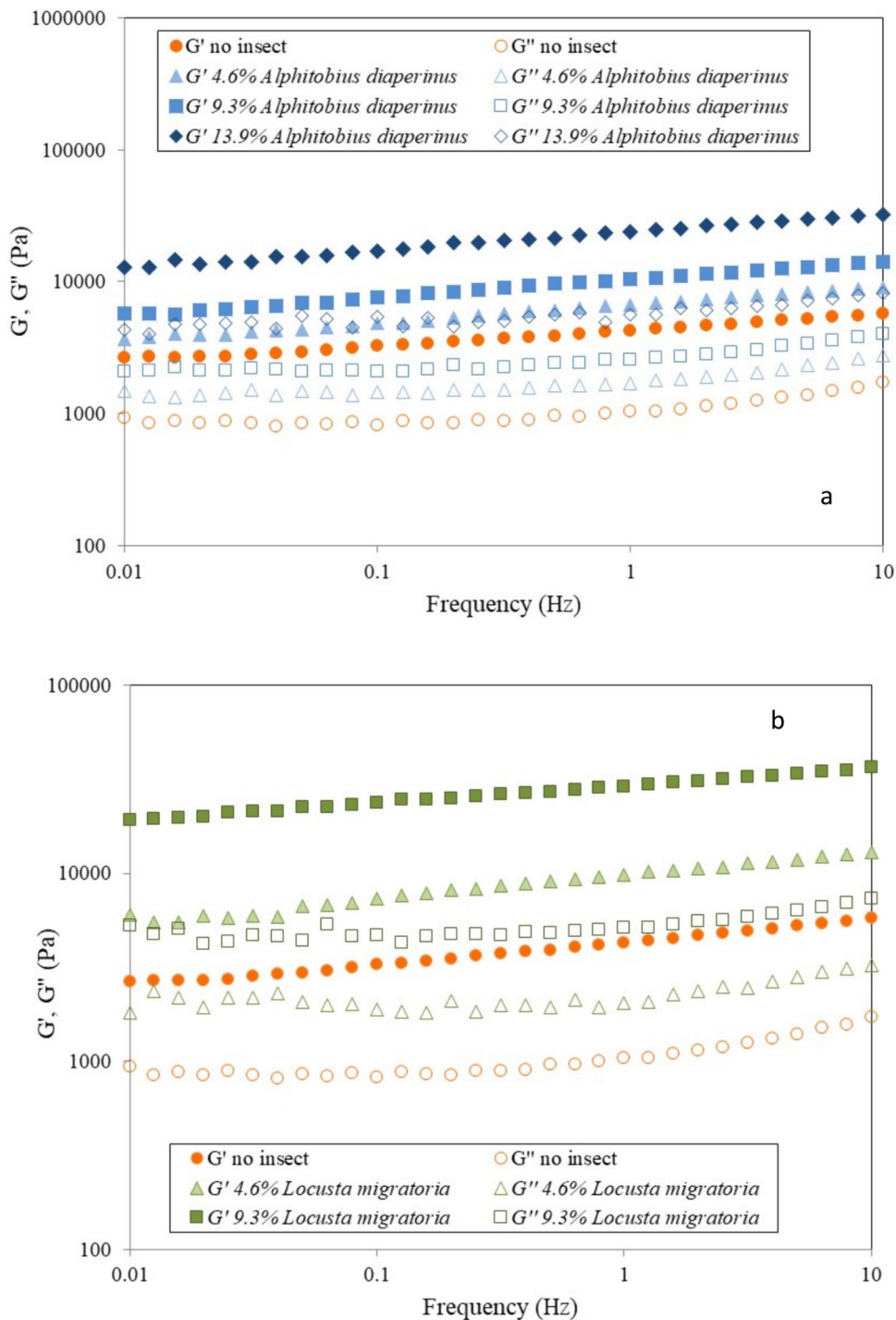
Samples	<i>Alphitobius diaperinus</i>		<i>Locusta migratoria</i>	
	$\eta_1$ (Pa s)	$n$	$\eta_1$ (Pa s)	$n$
<b>Control</b>	320.2a	0.274a	320.2a	0.274a
<b>4.6%</b>	444.3b	0.203b	623.8ab	0.125ab
<b>9.3%</b>	702.3c	0.153c	717.3ab	0.080ab
<b>13.9%</b>	1111.0d	0.092d	1084.5b	-0.078b

Means in the same column with the same letter do not differ significantly ( $p < 0.05$ ) according to Fisher's test

A difference in flow behaviour was observed between the dough enriched with *A. diaperinus* and *L. migratoria* powders. In both cases, the inclusion of insect powder raised viscosity values and the degree of pseudoplasticity (values of  $n$  closer to 0); however, the impact on pseudoplasticity was more noticeable in the dough enriched with *L. migratoria*, with  $n$  values lower than those of *A. diaperinus* (Table 1). The rise in viscosity and pseudoplasticity are acknowledged

positive factors for printability. In the case of grasshopper dough, the greater heterogeneity of the powder, caused by retained pieces of exoskeleton, as compared to buffalo powder, could explain the inability to print this dough, even at lower concentrations. González et al. (2019) also found an increase in dough consistency when insect powder was added to wheat flour, which resulted in a slight increase in dough development time and stability was obtained when

**Fig. 3** Mechanical spectra of chickpea dough enriched with edible. **a** *Alphitobius diaperinus*, **b** *Locusta migratoria* powders



**Table 2** Viscoelastic parameters of dough samples

Samples	<i>A. diaperinus</i> powder			<i>L. migratoria</i> powder		
	G' (Pa)	G'' (Pa)	tan $\delta$	G' (Pa)	G'' (Pa)	tan $\delta$
Control	4016a	978a	0.243a	4016a	978a	0.243a
4.6%	6502a	1665a	0.252a	18266a	2862a	0.173a
9.3%	10392b	2505b	0.241ab	22309a	4298a	0.199a
13.9%	22586c	5193c	0.229b	77305a	13725a	0.196a

Means in the same column with the same letter do not differ significantly ( $p < 0.05$ ) according to Fisher's test

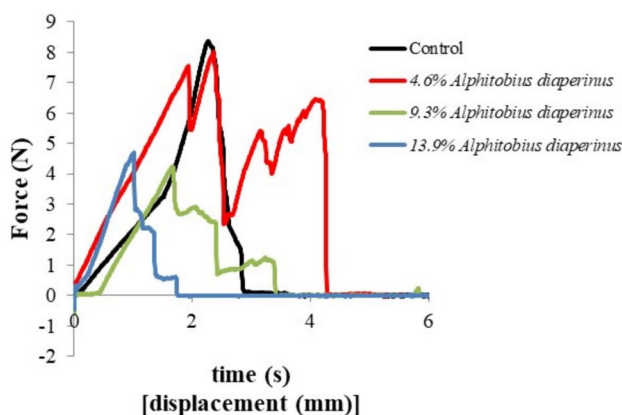
*Acheta domestica* or *Hermetia illucens* was added compared to the control.

### Viscoelastic Properties

Solid-like viscoelastic behaviour is necessary for extrusion-type 3D printing because liquid-like food cannot be shaped in an extrusion-type 3D printer (Pulatsu et al., 2020; Su et al., 2019). The values of the elastic moduli (G') and the viscous moduli (G'') versus frequency are shown in Fig. 3. The mechanical strength and self-supporting properties of the inks have been linked to the values of G' and G'', as reported by Chen et al. (2022). The results revealed a predominance of the solid/elastic component (G') over the liquid/viscous component (G''), which is suitable for 3D printing. The viscoelastic behaviour can be classified as typical of soft gels, with values of G' always higher than G'' and softly dependent on frequency. In the dough made with 13.9% *L. migratoria*, viscoelastic properties could not be measured at frequency values  $< 0.5$  Hz due to its heterogeneity, thus is not represented in Fig. 3b.

In Table 2, the mean values of G', G'', and tan  $\delta$  (G''/G') at 1 Hz are shown. Enrichment with both types of insect powders increased the viscoelastic parameters, the increase higher for *L. migratoria* dough. For 13.9% *A. diaperinus*, G' values increase

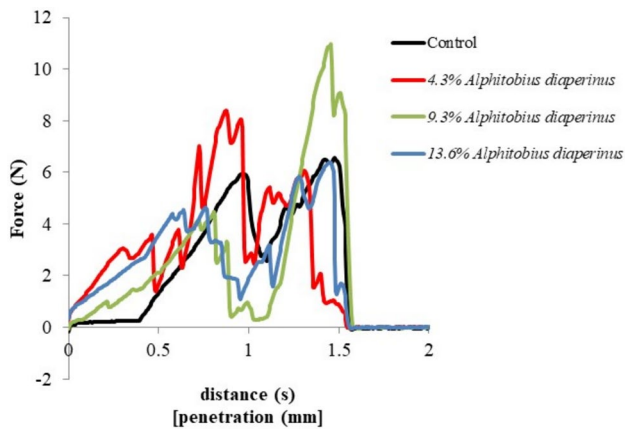
5.6 times compared to the control, from 4016 Pa (control) to 22,586 Pa (13.9% *A. diaperinus*); whereas for 13.9% *L. migratoria*, G' values increased 19.24 times (from 4016 Pa for the control to 77,304 Pa for 13.9% for *L. migratoria*). Therefore, the incorporation of *L. migratoria* powders has more effect on the viscoelastic properties of the dough than on the flow properties. For both types of insect powder, the increase in the amounts in the dough increase the values G' and G''. The tan  $\delta$  values (G''/G') in all frequency sweeps studied were less than 1, indicating the predominance of G' over G''. This illustrates the prevalence of the elastic component. In the *L. migratoria* doughs, the tan  $\delta$  values were lower than in the *A. diaperinus* at all concentrations, indicating a higher predominance of the elastic component in those samples. At all concentrations, *A. diaperinus* tan  $\delta$  values indicate the lowest contribution of elasticity than *L. migratoria* doughs, even at the lowest *L. migratoria* concentration (4.6%). The differences in viscoelasticity (relation amongst the viscous and elastic component) between the two types of insects objectively explain the observed differences in printability. Although a predominance of elastic versus the viscous moduli is required for an appropriate printability, a limitation in the value of G' and tan  $\delta$  was found. Thus, the greatest elasticity of *L. migratoria* dough at all the concentrations, together with the lowest values of tan  $\delta$ , did not allow for correct printability. Values of G' alone could not explain the differences in printability; for example, at the smallest *L. migratoria* amount (4.6%) added to the dough was not printable, whereas its G' values were lower than G' values for the *A. diaperinus* dough at 13.9%. Therefore, the best parameter to evaluate the printability in the doughs studied was tan  $\delta$ , with a limit value level of 0.2, below which the dough would be too elastic to be printed. Regarding the limit values of G, their maximum level will depend on the values of tan  $\delta$ . Therefore, G' values alone were not suitable to explain the differences in printability, but tan  $\delta$  was. The interpretation of these results should also consider the negative contribution of *L. migratoria* powder heterogeneity to printability at all concentrations studied.



**Fig. 4** Three-point break representative curve profiles of 3D-printed baked snacks

### Texture

The textural profiles of the 3D-printed baked snacks prepared with the *A. diaperinus* doughs are shown in Figs. 4



**Fig. 5** Penetration representative curve profiles of 3D-printed baked snacks

**Table 3** Textural parameters of 3D-printed baked snacks

Samples	Bending test	Penetration test	
	Breaking force (N)	Area under the curve (N.s)	Number of force peaks
No insect	9.94a	5.927a	3.4a
4.6% <i>Alphitobius diaperinus</i>	7.55ab	5.374ab	7.5b
9.3% <i>Alphitobius diaperinus</i>	5.49b	4.056b	6.5b
13.9% <i>Alphitobius diaperinus</i>	4.76b	4.590ab	

Means in the same column with the same letter do not differ significantly ( $p < 0.05$ ) according to Fisher's test

and 5. Each curve is a representative profile of each sample. Figure 4 represents curve profiles of the bending test that measure the force required to break a snack in half. Figure 5 shows the profiles of the penetration test which imitate the force required to bite the snack. In the bending test, the force curves of the snacks with 4.6% insect powder added were like those of the control snack, whereas the other snacks with a higher amount of *A. diaperinus* had a lower hardness compared to the control sample. However, in the penetration test, all curve profiles were similar, although the curves of snacks prepared using dough enriched with *A. diaperinus* powder showed a more jagged appearance with several fracture events typical of crispy food compared to control snacks (Chen et al., 2005).

The textural parameters (Table 3) were calculated from the texture profiles to provide a better analysis of these textural differences. It was observed in the texture profiles of the bending test that there were no significant differences in breaking force between the control sample and the 4.6% insect powder added. However, higher concentrations of insect powder led to lower breaking force. In the penetration test, the snacks prepared with insect powder had a more crispy behaviour than the control sample (greater number of force peaks), but slightly significant differences in the hardness were found in the penetration test. In both tests, no significant differences in hardness were found

between snacks prepared with insect powder. Therefore, insect powder increased crispness in this type of snack.

Different texture results were obtained for snacks acquired through the addition of insect powder. Ogunlakin et al. (2018) studied the quality of wheat biscuit fortified with edible termites (*Macrotermes nigeriensis*) and found that the break strength of the biscuit was reduced with an increase in the level of termite flour inclusion, although the insect partial substitute for wheat in biscuit production up to 20% does not affect the biscuit quality. Biró et al. (2020) assessed the hardness of oat biscuits enriched with cricket powder using the three-point rig test. Their findings indicate that the addition of cricket powder up to 15% did not significantly impact the texture of the samples, although a slight increase in hardness was observed with higher levels of cricket concentration. Severini et al. (2018) concluded that there was no discernible effect

on hardness with different insect enrichments in their study on 3D-printed snacks enhanced with edible insects. Although hardness increased with the level of insect enrichment at higher temperatures (220 °C), the behaviour of hardness as a function of baking temperature was not linear, with a decrease in hardness at intermediate baking temperatures (180–185 °C).

## Conclusions

In this study, the effect of *A. diaperinus* and *L. migratoria* on the flow and linear viscoelastic properties of a salty snack formula was studied and related to printability properties. *L. migratoria* showed a greater increase in viscosity and pseudo-plasticity than *L. diaperinus*. In both types of insect powder, the increases in concentration increase viscosity and pseudo-plasticity. The linear viscoelastic properties showed a predominance of the elastic modulus ( $G'$ ) versus the viscous modulus ( $G''$ ) in all doughs, with the highest elastic contribution shown by *L. migratoria*. Although a predominance of elastic versus the viscous moduli is required for appropriate printability, the highest elasticity (lowest  $\tan \delta$ ) of *L. migratoria* made it unsuitable for printing. A  $\tan \delta$  of 0.2 was set as the limit value, below which the dough would be too elastic to be printed.

Salty snacks with a texture profile similar as the control (no insect) were found with 4.6% *L. migratoria* incorporation. A higher concentration of *L. migratoria* resulted in increased crispiness. Incorporating *L. migratoria* up to a concentration of 13.9% demonstrated optimal dough rheological properties for printing and yielded optimal texture for the 3D-printed salty snacks.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s11947-024-03437-6>.

**Author Contribution** Nerea García-Gutiérrez conducted the experiments. Ana Salvador and Teresa Sanz designed the investigation, formal analysis, writing—review and editing. Montse Ferrando, Carme Güell, and Carmen Mendez conducted some experiments, and Silvia de Lamo Castellvi made the conceptualization, supervision, review and editing.

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**Data Availability** Data will be made available on request.

## Declarations

**Competing Interests** The authors declare no competing interests.

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