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Exploring the potential use of two species of *Dioscorea* in composite flours for bakery products

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Abstract: *Dioscorea species* possess valuable properties that make them suitable for use in food production. This study characterised doughs made with flours from two species of *Dioscorea* by evaluating their nutritional, rheological and textural properties for use in baking. *Dioscorea composita* flour had a higher crude fibre content (1.5% ± 0.11), while *Dioscorea bulbifera* flour exhibited higher antioxidant content [930.5 mg GAE · (100 g)$^{-1}$ dry matter] and better protein digestibility (89.06% ± 0.7%). Wheat flour was substituted with *Dioscorea* flour (0–30%) to make composite doughs. Doughs containing *D. composita* exhibited superior biaxial extensibility (41.22 ± 11.9 mm at 20% substitution), compared to the control (21.4 ± 2.7 mm), indicating their potential for use in bread production. Meanwhile, doughs containing 20% or more *D. bulbifera* flour were more suitable for products such as biscuits or pitta bread. However, all composite doughs were harder to handle, likely due to gluten dilution and component interactions, regardless of the *Dioscorea* species used. Therefore, the *Dioscorea* species used in this study could be considered promising candidates for inclusion in suitable bakery products.

Keywords: dough properties; bread making, dough rheology; textural analysis

The genus *Dioscorea* has about 25 edible species, of which more than 600 have significant economic value (Adoméniené and Venskutonis 2022). However, the taxonomic knowledge of the *Dioscoreaceae* family remains limited. In Mexico, *Dioscorea bulbifera* and *Dioscorea composita* have been identified as having significant potential for industrial food applications. The edible portion of the former is an aerial structure that develops in the central axis of its leaves, known as bulbil, while the edible part of the latter is the plant structure growing underground as a tuber. The nutritional and functional attributes of *Dioscorea bulbifera* have been thoroughly investigated and described in the scientific literature. Several studies (Jiménez-Montero and Sánchez Silvera 2017; Olatoye and Arueya 2019; Souza et al. 2021; Dhore et al. 2023) have detailed its composition and potential health benefits, highlighting its relevance in food science and nutrition. A recent review by Wang et al. (2025) provides a comprehensive overview of the bioactive constituents present in various *Dioscorea* species, including *D. bulbifera*, and discusses their potential in food product development. Additionally, Tareen et al. (2025) emphasise the significance of *Dioscorea* species as functional foods, noting

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their contribution to dietary diversity and their possible role in the prevention and management of non-communicable diseases. Collectively, these findings support the consideration of *D. bulbifera* as a valuable ingredient for enhancing the nutritional profile and functional qualities of bakery products. However, there is a notable lack of recent data concerning the nutritional attributes of *D. composita*, with the manuscript of Arrioja (1976) being the most recent source available. There is, therefore, considerable opportunity for further research into its nutritional and functional properties. Both plant structures, bulbils and tubers, are mainly composed of starch, making them suitable raw materials for obtaining flours, used to formulate bakery products. The interest in the use of composite flours in bakery products has increased significantly. The term 'composite flour' is used to describe a blend of starchy tuber flours, such as cassava, yam and potato, and protein-rich flours and cereals that are formulated to have specific functional properties and nutritional composition. The nutritional value of composite flour has been shown to exceed that of flour milled from a single cereal, in terms of minerals, vitamins, fibres and proteins (Hasmadi et al. 2020). *Dioscorea* species have been employed in the formulation of composite flours, which have been used to obtain a range of food products, including noodles, snacks, baby food, tortillas and bread (Eke and Owuno 2012; Asiyanbi-Hammed 2016; Induar et al. 2021). Therefore, this study aims to analyse the chemical and functional properties of flours derived from the bulbs of *D. bulbifera* and the tubers of *D. composita*, and to develop composite doughs by blending these flours with wheat flour in varying proportions, for use in suitable bakery products.

MATERIAL AND METHODS

Briefly, this study focused on the comprehensive characterisation of flours derived from two species of *Dioscorea*, specifically analysing their chemical and functional properties. The evaluation included measurements of phenolic content and antioxidant activity, to determine the potential health benefits of these flours. Subsequently, the *Dioscorea* flours were blended with wheat flour to create composite doughs. These doughs were then assessed for their texture and rheological behaviour. The primary aim was to test the hypothesis that doughs formulated with varying ratios of *Dioscorea* and wheat flours would exhibit unique nutritional and techno-functional properties, thereby making them suitable for diverse bakery applications.

Plant material. Bulbils from *D. bulbifera* at full physiological maturity and tubers from *D. composita* collected one year after being sown were randomly selected from spontaneously growing plants in Zapotitlan de Mendez, northern Puebla State, Mexico (19° 58' 10" N, 97° 38' 36" W, 640 m above sea level). This region features a warm, humid climate with heavy summer rainfall and is classified as *Aw* under the Köppen classification (García 2004). Both the bulbils of *D. bulbifera* and the tubers of *D. composita* were stored at 4 °C until further use.

Sample preparation. The plant materials were thoroughly washed and brushed to eliminate any solid residue, after which the exocarp was discarded. Slices with a thickness of 0.5 cm were obtained and immediately submerged in a 3% w/v citric acid solution at 25 °C for 5 min to prevent enzymatic oxidation. The slices were washed thrice with fresh water to ensure complete removal of citric acid. The slices were dried in a forced air convection oven (HCF-82D, Riossa, Mexico) at 55 °C for 72 h. Following this, the dried slices were ground in a grinder (ME-700Y, Semillas de Vida, Mexico) and sieved through a 100 mesh (149 μm, Montinox, Mexico). The samples were then stored in plastic bags at room temperature until use.

Chemical characterisation of flours. In order to fulfil the objectives pertaining to the chemical characterisation of flours, analyses were conducted on *D. bulbifera* and *D. composita* flours for moisture content (method 925.10), ash content (942.05), ether extract content (920.85), crude protein content (951.03), and crude fibre content (962.09), following AOAC (2019) protocols. Carbohydrate content was determined by calculation as the difference.

Digestibility of protein in flour. To facilitate a comprehensive discussion of the protein content observed in the chemical analysis of *Dioscorea* spp. flours, protein digestibility was assessed according to the AOAC (2019) method 971.09.

Total phenolic content and antioxidant capacity. In order to address the objective concerning the functional properties of the flours, the total phenolic content (TPC) was measured using the Folin-Ciocalteu method, as described by García et al. (2015). The antioxidant capacity of the samples was evaluated through the ABTS+ and DPPH radical scavenging assays, following the methodologies established by Brand-Williams et al. (1995), Re et al. (1999) and Kuskoski et al. (2005). These parameters enabled a comprehensive assessment of the ability of the flours to act as sources of bioactive compounds with potential health benefits.

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Dough rheology and textural analysis. To address the objective concerning dough characterisation in terms of texture and rheology, texture profile analysis, biaxial extensibility, uniaxial extensibility, Chen–Hoseney stickiness tests were conducted. A commercial extra fine wheat flour (San Antonio Tres Estrellas, Mexico) was used as the control sample.

The texture profile analysis (TPA) was made using 16 g of flour from each treatment and 10 mL of water, resulting in a sample of 25 g with a spherical shape. This was then left to stand for 20 min in a cylindrical container, before being placed in a texture analyser (TA.XT Plus, Stable Micro Systems, England) using a 30 kg load cell. The sample was compressed twice using a 25 mm cylinder probe (TA-3000) at a speed of 0.5 $mm \cdot s^{-1}$ and 20% deformation, with a 5 s rest period between each compression. The parameters of hardness, adhesiveness, resilience, cohesiveness, chewiness and springiness were obtained in accordance with the recommendations set out by Bourne (1978). Biaxial extensibility consists of two steps: first, 200 g of flour and 121 mL of a 2.5% (w/v) sodium chloride solution were mixed in a stainless steel bowl to obtain a dough. This dough was rolled out on a board to obtain five circular samples of 8 mm thickness using a 90 mm diameter cutter, then placed in the dough inflation pots and compressed for 30 s. At this time, the pots were protected with an acrylic cover and left to rest for 30 min. In the second step, the dough inflation pots were placed on the texture analyser coupled to the Dobraszczyk/Roberts model D/R2 dough inflation system. The samples were then placed on the inflation platform, where air was injected at a constant pressure to form a bubble until it burst. The dough firmness P (mm H_2O), extensibility L (mm) and strength W (10^{-4} J) were recorded, and the P/L ratio was calculated using the method 54–30.02 (AACC 2000). To measure uniaxial extensibility, 8 g of flour and 5 mL of distilled water were used to form a dough. The dough was placed in a Kieffer press and allowed to stand for 30 min, then the strips of dough were removed from the press with a spatula and positioned one by one in the Kieffer attachment (Kieffer et al. 1998) to perform the tensile test using a texture analyser with a TA53 probe, moving at a constant speed of 0.5 $mm \cdot s^{-1}$ until breaking. The resistance parameters to elongation and elongation force were obtained from the distance versus force graph, according to method 54-10.01 (AACC 2000).

The Chen–Hoseney stickiness test was performed by mixing 4 g of flour and 2.5 mL of distilled water and transferring to a stainless steel cell. The dough was then extruded through the sieve openings (14 mesh) by rotating the plunger. A spatula was used to remove the extrudate from the cell surface. An acrylic cover was then placed over the cell to minimise moisture loss from the dough. A texture analyser was fitted with a 25 mm diameter acrylic probe, the test speed was 0.5 $mm \cdot s^{-1}$, and the stickiness, cohesiveness, and work of adhesion parameters were obtained (Chen and Hoseney 1995).

Statistical analysis. All analyses were performed in triplicate using a completely randomised design. Chemical characterisation data were subjected to t-student tests and other variables to analysis of variance, using SAS software (v. 9.0., SAS Institute, USA). Means were compared using the Tukey test at $P \leq 0.05$.

RESULTS AND DISCUSSION

The chemical composition of *Discorea* flour is shown in Table 1. There were no significant differences ($P > 0.05$) in dry matter content and ether extract between the *Discorea* species studied. Similar dry matter values have been reported in preheated *D. bulbifera* (Ayo et al. 2018) and in flours derived from 15 cultivars of *D. bulbifera* (Olatoye and Arueya 2019). Furthermore, the dry matter in *D. composita* flours is consistent with reports of *Dioscorea* tubers (Yalindua et al. 2021). However, the ether extract values obtained in this study are lower than those reported for aerial yam or bulbils (Olatoye and Arueya 2019). The cultivar DBT3075 was reported as the source of flour with the lowest ether extract content (0.51%), which is higher than the values found in this study for *D. bulbifera*. Conversely, Yalindua et al. (2021) documented values ranging from 0.07% to 0.65% for *D. alata* tubers. With regard to ash content, crude protein, and soluble carbohydrates, *D. bulbifera* showed higher concentrations ($P \leq 0.05$) compared to *D. composita*. Despite the wide intervals reported for the bulbils of *D. bulbifera* and the *Dioscorea* tubers, the values found in this study are in the range of the highest contents reported when comparing different cultivars of *D. bulbifera* bulbils flour and different accessions of *Dioscorea* tuber flour, respectively (Olatoye and Arueya 2019; Yalindua et al. 2021). Conversely, the crude fibre content in *D. composita* was found to be higher than that in *D. bulbifera* ($P \leq 0.05$). It is noteworthy that the plant structures examined differ (bulbils for *D. bulbifera* and tubers for *D. composita*), and the greater crude fibre content observed in tubers ($P \leq 0.05$) is a distinctive feature. These species-specific differences may have implications for the textural properties of the resulting doughs. *D. composita* flour has a typical crude fibre content of between 1% and 6% for

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Table 1. Proximate composition, phenolic content, antioxidant capacity and protein digestibility of flours obtained from *Dioscorea bulbifera* bulbils and *Dioscorea composita* tubers

Variable	Flour source	
	D. bulbifera bulbils	*D. composita* tubers
Dry matter (%)	91.56 ± 0.15[a]	91.13 ± 0.30[a]
Ash (% DM)	4.70 ± 0.25[a]	4.27 ± 0.09[b]
Crude protein (% DM)	8.54 ± 0.11[a]	8.19 ± 0.14[b]
Ether extract (% DM)	0.46 ± 0.16[a]	0.43 ± 0.03[a]
Crude fibre (% DM)	0.09 ± 0.06[b]	1.50 ± 0.11[a]
Carbohydrates (% DM)	86.75 ± 0.16[a]	85.02 ± 0.27[b]
TPC [mg GAE·(100 g)$^{-1}$ DM]	930.50 ± 37.7[a]	397.00 ± 18.8[b]
DPPH [mg GAE·(100 g)$^{-1}$ DM]	113.54 ± 1.0[a]	25.64 ± 0.5[b]
ABTS [mg GAE·(100 g)$^{-1}$ DM]	360.67 ± 12.5[a]	158.71 ± 23.1[b]
Protein digestibility (%)	89.06 ± 0.7[a]	81.27 ± 0.2[b]

[a,b] different letters indicate statistical differences between (t-test, $P \leq 0.05$)
DM – dry matter; TPC – total phenolic content; DPPH – antioxidant capacity measured by DPPH radical scavenging; ABTS – antioxidant capacity measured by ABTS radical scavenging

yam flours (Tareen et al. 2025), while *D. bulbifera* bulbil flour contains very little crude fibre. Manufacturers of products requiring structural integrity and nutritional value, especially composite flours with wheat, should opt for *D. composita* flour, due to its higher fibre levels and associated benefits.

Analysis of the total phenolic content (TPC) and antioxidant activity, as measured by DPPH and ABTS radical scavenging assays, revealed significant differences between the two flours under study. Specifically, flour produced from *D. bulbifera* bulbils exhibited markedly higher values for all three parameters ($P \leq 0.05$) than flour derived from *D. composita* tubers. The TPC of *D. bulbifera* flour was found to be approximately twice that of *D. composita* flour. This finding is consistent with the range of TPC values reported for different *Dioscorea* varieties, spanning from 50.95 to 3 664.26 mg GAE·(100 g)$^{-1}$ of dry matter. Furthermore, the antioxidant capacity of *D. bulbifera* flour, as determined by DPPH and ABTS radical scavenging assays, was four and two times higher, respectively, than that of *D. composita* flour. Padhan et al. (2020) also identified wild yams, especially *D. bulbifera*, as being rich in bioactive compounds, with a measured phenolic content of 9.62 mg GAE·(100 g)$^{-1}$ of dry matter. The differences in phenolic compounds observed between these two *Dioscorea* species may be due to variations in their chemical composition, including the presence of sugars, carotenoids, and other compounds, as suggested by Bhandari and Kawataba (2004). These results strongly suggest that flour from *D. bulbifera* bulbils is a particularly potent source of antioxidants and could be a valuable addition to functional foods. Since *D. bulbifera* flour contains more antioxidants and less crude fibre, manufacturers may find it suitable for products requiring a soft texture, bright colour, and enhanced functional qualities. As well as its appealing sensory traits, the high antioxidant levels boost its functional value, and its bioactive compounds may promote health.

The protein digestibility of flour derived from *D. bulbifera* bulbils was found to be significantly higher ($P \leq 0.05$) than that of flour obtained from *D. composita* tubers, with an average difference of 8%. This increased digestibility reflects the proportion of digestible protein relative to the total protein content (Table 1). Higher protein digestibility implies a greater rate of absorption and utilisation of protein within the small intestine. While information on the protein digestibility of flours from *Dioscorea* species is limited, the values reported in this study suggest that these flours are a high-quality protein source. This is attributed to their sufficient levels of essential amino acids, as documented in previous studies on *Dioscorea* species (Wu et al. 2016; Doss et al. 2019; Eneogwe et al. 2023). These results suggest that both flours can contribute to the nutritional profile of doughs made with composite flours, and can therefore be used as an alternative to traditional wheat flour to improve the amino acid profile of baked goods. These findings could be used by manufacturers to justify the use of *Dioscorea* spp. flours to improve the amino acid profile of wheat-based food products, which are known to be low in the essential amino acid lysine

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(Tul-Noor et al. 2025). This could enhance the nutritional value and protein quality of bread, biscuits, pasta, and other cereals, eliminating the need for expensive added proteins or amino acids.

Table 2 shows the uniaxial and biaxial extensibility results for composite flour doughs containing various proportions of *D. bulbifera* flour within a wheat flour matrix. These tests were performed to evaluate the potential of the composite doughs for use in bakery products, particularly in terms of their impact on dough handling and baking processes. Regarding uniaxial extensibility, the composite doughs exhibited lower resistance and extensibility values than the control dough made entirely of wheat flour ($P \leq 0.05$). However, there were no significant differences between the composite doughs. It is important to note that extensibility and resistance are related to the substitution of wheat flour with yam flour (Li et al. 2012). Furthermore, Li et al. (2020) hypothesised that dough breakdown is due to the total energy required, as reflected in dough extensibility. These results suggest that doughs made from composite flours with *D. bulbifera* may be less malleable and more difficult to handle than the control dough. Therefore, it would be sensible for manufacturers to ensure that *D. bulbifera* accounts for no more than 30% of wheat composite flours, since using a higher proportion could make handling more difficult.

On the other hand, it has been shown that biaxial parameters are reliable indicators of flour suitability for bread making. Data relating to maximum pressure (P) showed a significant increase in composite doughs compared to the control group ($P \leq 0.05$). The mean P value increased with the level of *D. bulbifera* flour incorporated into the composite dough. This parameter relates to tenacity, or the resistance to deformation. In essence, it indicates how firm or elastic the dough is under stress. For extensibility (L), no statistically significant difference ($P > 0.05$) was observed between the control and composite doughs containing 10% *D. bulbifera* flour. However, the L values for composite doughs containing 20% and 30% *D. bulbifera* flour were significantly lower ($P \leq 0.05$) than the control. These results suggest that *D. bulbifera* flour negatively affects the extensibility of dough when stretched in two directions under pressure. Therefore, manufacturers should avoid using more than 20% *D. bulbifera* flour in products that require dough expansion, such as pizza or sandwich bread. Regarding tenacity (P/L), no statistical difference was observed between the control and the composite dough containing 10% *D. bulbifera* flour. However, as the proportion of *D. bulbifera* flour increases, so does the P/L value. The higher tenacity exhibited by doughs with a higher proportion of *D. bulbifera* flour suggests they would be more resilient and less malleable, making them harder to stretch or mould. Soro et al. (2020) replaced up to 25% of wheat flour with *D. praehensilis*, resulting in all biaxial extensibility parameters exceeding those of the control. This suggests that high levels of these parameters are not conducive to optimal breadmaking. Ultimately, no statistically significant differences ($P > 0.05$) were observed among the treatments, including the control, with respect to baking strength (W). This parameter is closely related to dough quality during the baking process and mainly indicates the ability of doughs to retain gases during fermentation and baking (Kumar et al. 2020). This affects the volume, crumb, and texture of the final product. A similar result was reported by Gül and Şen (2017) in a study in which rosehip seed flour was

Table 2. Extensibility of the doughs obtained from a composite flour containing *Dioscorea bulbifera*

Parameter	Treatments			
	C	10DB	20DB	30DB
Uniaxial extensibility				
Resistance (N)	0.35 ± 0.05^{a}	0.08 ± 0.02^{b}	0.05 ± 0.02^{b}	0.057 ± 0.05^{b}
Extensibility (mm)	34.85 ± 1.59^{a}	22.40 ± 0.54^{b}	19.66 ± 2.04^{b}	21.02 ± 14.75^{b}
Biaxial extensibility				
P (mm H_2O)	127.6 ± 72.6^{c}	309.6 ± 50.6^{b}	380.2 ± 56.2^{b}	757.6 ± 72.6^{a}
L (mm)	21.5 ± 2.9^{a}	26.3 ± 2.4^{a}	4.1 ± 2.3^{b}	4.7 ± 2.9^{b}
P/L	6.3 ± 22.8^{c}	11.6 ± 24.9^{c}	100.3 ± 17.7^{b}	274.1 ± 22.8^{a}
W (kPa)	94.6 ± 31.6^{a}	105.0 ± 14.9^{a}	82.2 ± 23.3^{a}	119.3 ± 21.8^{a}

[a–c] different letters between columns indicate a significant difference according to the Tukey test ($P \leq 0.05$)

C – control (100% wheat flour); 30DB, 20DB and 10DB – treatments with 30, 20, and 10% added of *D. bulbifera* flour; P – maximum pressure; L – dough extensibility; P/L – tenacity; W – baking strength

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used instead of wheat flour. They attributed the results of these experiments to the addition of rosehip seed flour, which led to changes in the gluten matrix and reduced gas retention and volume in the baked product. As a result, incorporating *D. bulbifera* into bread is not advised; instead, it is more suitable for use in the production of bakery items, such as biscuits.

As shown in Table 3, the uniaxial and biaxial extensibility of composite doughs was studied at different levels of *D. composita* flour in wheat flour. For uniaxial extensibility, the resistance values at 10% and 20% *D. composita* were not significantly different ($P > 0.05$). However, these values were significantly lower than those observed in the control group ($P \leq 0.05$). However, when 30% *D. composita* flour was used, the dough showed a significantly lower resistance ($P \leq 0.05$). This behaviour is similar to that observed in composite doughs made with *D. bulbifera*. Although the extensibility values did not differ significantly between treatments ($P > 0.05$), they were significantly lower than the control ($P \leq 0.05$). Therefore, it can be inferred that the composite doughs would be more difficult to handle than the control dough.

Conversely, the dough containing 10% *D. composita* flour had a maximum pressure (P) value that differed significantly from the control. Meanwhile, the doughs containing 20% and 30% *D. composita* flour had higher P values than the control, but these were not significantly different from each other. These results suggest that composite doughs are firmer than the control. Nevertheless, the maximum value for dough extensibility (L) was observed at 20% *D. composita* flour ($P \leq 0.05$), indicating that, despite being firmer, the dough is biaxially more extensible than the control. This makes this type of dough more suitable for bread making, where high L values are desired. No significant differences were found between the other treatments and the control ($P > 0.05$), indicating that the effect of adding *D. composita* flour on the biaxial extensibility of the doughs ranged from positive to null.

Tenacity (P/L) increased significantly ($P \leq 0.05$) with the addition of 20% *D. composita* flour, and baking strength (W) increased in all treatments compared to the control ($P \leq 0.05$), with no significant differences between treatments ($P > 0.05$). These results may be of interest to manufacturers, since adding *D. composita* flour produces dough that is firmer and more resistant, both of which are considered advantageous qualities in bread production. The biaxial extensibility parameters P and P/L of composite doughs containing 20% and 30% *D. composita* were lower than those containing *D. bulbifera* flour, the former having a lower protein content than the latter. It is therefore hypothesised that composite doughs containing 20% and 30% *D. composita* flour are more suitable for bread making than those containing *D. bulbifera* flour. This is due to the fact that the quantity of protein present in the dough has an impact on its characteristics, by means of the embedding of the starch granules through the formation of the gluten matrix (Tronsmo et al. 2003). Despite the addition of *D. composita* flour diluting the gluten concentration, the protein of *D. composita* can interact with the gluten and starch granules to provide a composite matrix. In this matrix, the proteins of both flours provide elasticity, while the starch granules add rigidity to the dough (Ren et al. 2020).

The Chen-Hoseney and TPA parameters of the doughs obtained from a composite flour containing

Table 3. Extensibility of the doughs obtained from a composite flour containing *Dioscorea composita*

Parameter	Treatments			
	C	10DC	20DC	30DC
Uniaxial extensibility				
Resistance (N)	0.34 ± 0.05^a	0.10 ± 0.03^b	0.11 ± 0.03^b	0.05 ± 0.01^c
Extensibility (mm)	32.58 ± 1.61^a	20.2 ± 4.37^b	19.45 ± 2.10^b	19.39 ± 2.89^b
Biaxial extensibility				
P (mm H_2O)	126.6 ± 63.6^c	220.9 ± 48.1^b	319.3 ± 48.1^a	324.6 ± 56.9^a
L (mm)	21.4 ± 2.7^b	25.8 ± 11.9^b	41.22 ± 11.9^a	22.9 ± 10.0^b
P/L	6.8 ± 13.3^c	11.9 ± 10.0^c	21.7 ± 10.0^b	32.3 ± 11.9^a
W (kPa)	93.6 ± 25.7^b	113.3 ± 20.4^a	110.1 ± 20.4^a	118.8 ± 24.6^a

$^{a-c}$ different letters between columns indicate a significant difference according to the Tukey test ($P \leq 0.05$)
C – control (100% wheat flour); 30DB, 20DB and 10DB – treatments with 30, 20, and 10% added of *D. composita* flour; P – maximum pressure; L – dough extensibility; P/L – tenacity; W – baking strength

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D. bulbifera are presented in Table 4. The results show that there is no statistically significant difference (P < 0.05) between the treatments and the control in terms of stickiness. This outcome is favourable for the dough handling process, as the surface adhesion during processing would not be excessive enough to impede the handling of the dough. However, adhesiveness and cohesiveness show significantly higher values (P ≤ 0.05) for the control, compared to the treatments, although these differences were not statistically significant (P > 0.05) between the treatments. It is evident that the lower values of adhesiveness and cohesiveness are indicative of a dilution of gluten by the starch of *D. bulbifera*. This observation suggests the presence of a protein with distinct characteristics from *D. composita*, resulting in a weaker protein network compared to gluten. Nevertheless, the decrease in cohesiveness values is less pronounced than the decrease in adhesiveness. This can be explained by the role of the phenolic compounds found in high concentration in *D. bulbifera*. These compounds have the potential to form a complex with gluten and starch, compensating for the gluten dilution, as described by Girard and Awika (2020).

The TPA parameters demonstrated variability among the treatments and the control, with the exception of the resilience parameter. Regarding hardness, significant differences were observed among all treatments in comparison to the control group (P ≤ 0.05). Additionally, an increase in mean values was noted as the concentration of *D. bulbifera* flour increased. This trend underlines the impact of *D. bulbifera* flour on the textural properties of the dough, particularly its contribution to increased firmness as the substitution level rises. The cohesiveness value showed a significant increase (P ≤ 0.05) at 10% *D. bulbifera* use, indicating enhanced internal bonding within the dough matrix at this concentration. Following a gradual decrease with increasing *D. bulbifera* flour concentration, the results reached a plateau at 30% *D. bulbifera*. It is noteworthy that the 30% *D. bulbifera* treatment did not demonstrate any statistically significant differences (P > 0.05) when compared to the control, indicating that higher concentrations of *D. bulbifera* did not further affect this textural property compared to the baseline wheat flour dough. A comparable result was obtained for springiness, which measures the extent to which a deformed dough recovers its original shape after being compressed. A significant increase (P ≤ 0.05) was observed when 10% *D. bulbifera* flour was used, and a gradual decrease was observed as the concentration of *D. bulbifera* flour increased. It is evident that the elastic component of the gluten network is enhanced at low substitution levels with *D. bulbifera*. However, at 20% substitution, the gluten network weakens due to the dilution of gluten caused by the addition of starch. The values obtained for 20 and 30% *D. bulbifera* were not significantly different from the control (P > 0.05). The chewiness parameter showed significantly different values for the treatments compared to the control (P ≤ 0.05), with an increase observed as the concentration of *D. bulbifera* was increased.

Table 4. Chen-Hoseney test and texture profile analysis (TPA) of the doughs obtained from a composite flour with *Dioscorea bulbifera*

Parameter	Treatments			
	C	10 DB	20 DB	30 DB
Chen-Hoseney test				
Stickiness (g)	19.94 ± 6.48^{a}	28.78 ± 6.90^{a}	28.22 ± 10.86^{a}	24.28 ± 3.57^{a}
Adhesiveness (g·s^{-1})	124.50 ± 30.33^{a}	95.34 ± 15.18^{b}	83.89 ± 25.69^{b}	75.07 ± 22.87^{b}
Cohesiveness (mm)	19.35 ± 10.83^{a}	13.67 ± 3.51^{b}	16.16 ± 6.03^{b}	15.88 ± 7.32^{b}
Texture profile analysis				
Hardness (N)	1.12 ± 0.63^{c}	3.11 ± 0.38^{b}	4.71 ± 2.62^{b}	6.52 ± 1.96^{a}
Resilience	0.08 ± 0.01^{a}	0.12 ± 0.03^{a}	0.10 ± 0.02^{a}	0.12 ± 0.09^{a}
Cohesiveness	0.34 ± 0.05^{b}	0.42 ± 0.04^{a}	0.40 ± 0.04^{a}	0.37 ± 0.04^{ab}
Springiness	0.39 ± 0.06^{c}	0.55 ± 0.05^{ab}	0.48 ± 0.10^{bc}	0.50 ± 0.13^{bc}
Chewiness (N)	0.13 ± 0.04^{c}	0.73 ± 0.17^{b}	0.83 ± 0.36^{ab}	1.16 ± 0.36^{a}

$^{a–c}$ different letters between columns indicate a significant difference according to the Tukey test (P ≤ 0.05)

C – treatment with 100% wheat flour; 10DB, 20DB and 30DB – treatments with 10, 20, and 30% of *D. bulbifera* flour, respectively

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This trend indicates that the addition of *D. bulbifera* flour has a measurable impact on the texture of the dough, as reflected in the chewiness values recorded during analysis. However, the TPA parameters in this study differed from those observed in other studies, mainly due to the use of composite flours from a different source than those documented in the literature (Yamul and Navarro 2020; Siddique et al. 2024).

The Chen–Hosseney and TPA parameters of the doughs obtained from a composite flour containing *D. composita* are presented in Table 5. A statistically significant difference ($P \leq 0.05$) was observed between the treatments and the control in terms of stickiness. As the concentration of *D. composita* increased, so too did the mean value of stickiness, reaching a maximum at 10% *D. composita* flour. Subsequent analysis revealed a slight decrease in the mean values at 20% and 30%, though these differences were not statistically significant ($P > 0.05$). An increased adhesiveness can complicate dough manipulation, as the dough tends to adhere more readily to surfaces during processing. Salve and Arya (2020) posit that stickiness is contingent on multiple factors, including gluten dilution. They substituted peanut flour for wheat flour in the dough to prepare flat bread, finding that stickiness increased with high levels of protein. In this work, the highest observed adhesiveness was recorded for the control treatment. By contrast, the adhesiveness exhibited by the treatment containing 10% *D. composita* flour was significantly lower ($P \leq 0.05$). The adhesiveness of doughs containing 20% and 30% *D. composita* flour was not significantly different from that of the control ($P > 0.05$). The behaviour of these composite doughs is characterised by higher stickiness and low adhesiveness, which leads to strong adhesion during dough handling in the early stages, but rapid release once the dough is lifted.

The TPA parameters showed analogous behaviour with respect to the *D. bulbifera* treatments, with resilience being the parameter that did not show statistically significant differences ($P > 0.05$) between the treatments and the control. For hardness, the mean values increased with increasing concentrations of *D. composita* flour. This trend suggests that, although the addition of *D. composita* flour leads to a dilution of gluten, the other components present in the flour interact in such a way that they compensate for the reduction in gluten, resulting in greater firmness of the dough. The value of cohesiveness increased significantly ($P \leq 0.05$) when 10% of *D. composita* was used, and then gradually decreased to values not significantly different from the control ($P > 0.05$) as the concentration of *D. composita* flour increased. Composite doughs with 20% and 30% *D. composita* were no longer statistically different from the control ($P > 0.05$). A similar behaviour was obtained for the springiness, where a significant increase ($P \leq 0.05$) was observed when 10% *D. composita* flour was used, and a gradual decrease was observed with increasing concentrations of *D. composita* flour. Finally, chewiness showed significantly different values for the treatments compared to the control ($P \leq 0.05$). This parameter showed a maximum value when 20% of *D. composita* flour was used. The value decreased until it reached a value

Table 5. Chen-Hoseney test and texture profile analysis (TPA) of the doughs obtained from a composite flour with *Dioscorea composita*

Parameter	Treatments			
	C	10 DC	20 DC	30 DC
Chen-Hoseney test				
Stickiness (g)	15.67 ± 3.64^b	40.43 ± 3.64^a	38.05 ± 3.33^a	33.36 ± 3.33^a
Adhesiveness (g·s^{-1})	125.21 ± 12.85^a	80.92 ± 12.85^b	100.98 ± 11.73^a	111.87 ± 11.73^a
Cohesiveness (mm)	21.44 ± 4.52^a	24.90 ± 4.52^a	22.01 ± 4.13^a	19.17 ± 4.13^a
Texture profile analysis				
Hardness (N)	1.12 ± 0.63^b	1.66 ± 0.86^b	3.67 ± 1.58^a	3.80 ± 0.60^a
Resilience	0.08 ± 0.01^a	0.09 ± 0.03^a	0.10 ± 0.01^a	0.09 ± 0.01^a
Cohesiveness	0.34 ± 0.05^b	0.47 ± 0.20^a	0.39 ± 0.04^b	0.33 ± 0.10^b
Springiness	0.39 ± 0.06^b	0.57 ± 0.23^a	0.43 ± 0.12^b	0.38 ± 0.12^b
Chewiness (N)	0.13 ± 0.05^c	0.45 ± 0.43^b	0.64 ± 0.34^a	0.49 ± 0.27^b

$^{a-c}$ different letters between columns indicate a significant difference according to the Tukey test ($P \leq 0.05$)

C – treatment with 100% wheat flour; 10DB, 20DB and 30DB – treatments with 10, 20, and 30% of *D. composita* flour, respectively

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that was not significantly different from the treatment with 10% *D. composita* flour ($P > 0.05$). The behaviour of the TPA parameters of doughs with *D. composita* is similar to that found with *D. bulbifera* in this work. However, when wheat flour is replaced by *Dioscorea* flour, a decrease in certain TPA parameters is observed, including resilience, cohesiveness and chewiness, suggesting that *Dioscorea* flour causes molecular disorder, resulting in the production of soft doughs (Yamul and Navarro 2020). Consequently, the replacement of wheat flour with *D. composita* or *D. bulbifera* in doughs at levels above 10% causes molecular disorder, leading to an increase in hardness and a decrease in adhesiveness. This phenomenon can be attributed to the interaction between starch and protein, which disrupts dough development (Ranasinghe et al. 2024).

CONCLUSION

The chemical analysis of the studied *Dioscorea* species revealed significant differences ($P \leq 0.05$) in most proximate components, except ether extract and dry matter, reflecting variations in origin and plant structure. *D. bulbifera* flour showed significantly higher total phenolic content, antioxidant capacity and protein digestibility ($P \leq 0.05$), making it more suitable for functional bakery products. Doughs made from composite flours are harder to handle, as determined by the uniaxial and biaxial extensibility and the Chen-Hoseney and texture profile analysis parameters, regardless of the type of *Dioscorea* flour used. However, it has been demonstrated that wheat flour substituted with *D. composita* is better suited for bread making, based on biaxial extensibility, than with *D. bulbifera*. Doughs containing composite flour from *D. bulbifera* can be utilised in products such as biscuits or pita bread, where high extensibility is not a prerequisite. Variations in *Dioscorea* species concentration in composite flours changed the rheological and textural properties of the doughs by diluting gluten with starch-rich *Dioscorea* flours. Therefore, the findings support the hypothesis presented. Further research should examine the amino acid profiles of composite doughs, and explore technological methods to increase the use of *Dioscorea bulbifera* and *Dioscorea composita* doughs in yeast-leavened and laminated bakery products.

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