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Original article

Comparison of vegetable powders as ingredients of flatbreads: technological and nutritional properties

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Summary Health-driven innovation is transforming bakery products, particularly with non-conventional ingredients. This study aimed to produce healthy and technologically acceptable flatbreads, exploring the inclusion (2%) of vegetable powders (black and green olives, orange peel, lemon, tomato, beetroot, carrot, onion, artichoke, spinach, chard, kale and pak choi). Spinach and chard increased the mineral content (1.42 and 1.30 g/ 100 g) respect to control (1.01 g/100 g). Fibre content ranged from 9.33 to 11.18 g/100 g when added onion, chard, pak choi, tomato or artichoke. Beetroot was the most effective changing the colour (ΔE^* 43.09), while tomato reduced the hardness (4.06 vs 5.29 N in the control). Lemon and tomato were effective reducing the extent of starch enzymatic hydrolysis by 65% and 34%, respectively. Vegetable powders can be innovative, natural, sustainable and healthy ingredients in the breadmaking of flatbreads. The incorporation of these non-conventional ingredients opens new opportunities for the bakery industry.

Keywords Bakery, bread, breadmaking, starch digestibility, texture.

Practitioner points

- Vegetable powders are sustainable ingredients for obtaining innovative bakery products.
- Flatbread physicochemical properties change depending on the type of vegetable addition.
- Vegetable powders enhance the nutritional profile of flatbreads, particularly fibre content and *in vitro* starch digestion.

Introduction

Flatbreads (FB) are worldwide one of the oldest-consumed breads, and maybe the first processed food, which are extensively consumed in the Mediterranean region. Conventionally, this type of bread is prepared from a flattened dough made of flour, water, salt and yeast (Paciulli *et al.*, 2021, Boukid, 2022, Garzon *et al.*, 2022, Pasqualone *et al.*, 2022). Flatbreads are very convenient baked foods owing to its short process and the existing variety of recipes (Pasqualone, 2018). Like other bakery foods, FB present elevated carbohydrate content, with high rapid digestible starch level, which is associated with an increase in glycaemic index (Boukid, 2022). Therefore, one important target has been to modify carbohydrate digestion, particularly starch digestion.

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Some previous studies proposed FB recipes incorporating fibres to change the glycemic response. Sharma & Gujral (2019) examined FB prepared with different millet powders, which led to higher slowly digestible starch (SDS) and resistant starch (RS) content, and lower glycemic index compared to wheat flatbread. Authors correlated the results with the higher content of fibre fraction in millet flatbreads. Likewise, the addition of legume and root flours (chickpea, soy, sweet potato and cassava) has been explored in whole grain FB reducing the glycemic response. These results were associated with the soluble fibre content, that could serve as a physical barrier in food, slowing down gastric emptying during digestion (Jordge *et al.*, 2022). De Angelis *et al.* (2023) proposed to increase protein and fibre content with dry-fractionated pea protein concentrate leading to an enriched gluten-free *focaccia* when using 5 g/100 g of pea protein, 20 g/100 g of corn and 20 g/100 g rice flour. Nevertheless, despite the interest in reducing the starch hydrolysis in this type of breads, there is still scarce information about other ingredients not commonly used in breadmaking.

There is a current trend to innovate and improve the nutritional profile through novel ingredients, such as, cereals, pseudocereals, spices herbs, vegetables or fruits (Dziki *et al.*, 2014; Hobbs *et al.*, 2014; Betoret & Rosell, 2020). The healthy profile of fruits and vegetables is widely recognised, attributed to their high content of bioactive compounds, such as fibre (pectin,

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cellulose, hemicellulose and lignin), minerals or phenolics compounds (Paciulli *et al.*, 2021, Gómez & Martinez, 2018) but their use in bakery products is rather limited to a few studies. Recently, Gasparre *et al.* (2024) developed gluten-free rice or corn flatbreads with different concentrations of orange peel (0, 3%, 6%, 9%) increasing fat, ash and fibre content. Likewise, onion peel (1%, 2%, 3%) was incorporated in wheat chapatti flatbread which decreased the hardness and elasticity due to the interference of onion fibre with the gluten network (Siddiqui *et al.*, 2022). Flatbreads with green leafy vegetables, like drumstick leaves powder (5%), showed higher content of protein, iron, calcium and carotenoids, enhancing their bioaccessibility (Bhavya & Prakash, 2021).

Previous studies integrating food industry by-products, specifically fruits or vegetables, into flatbread formulations have been based on the analysis of nutritional compounds and some technological properties. Despite this, limited studies have been focused on the influence of these compounds (fibre, minerals or polyphenols) on starch digestibility, and consequently their implications for the glycemic response. Waghmare & Arya (2014) obtained unleavened flatbread (*Thepla*), with various fruit by-products (apple pomaces, watermelon rinds and papaya peels) at different concentrations (3%, 6%, 9% w/w basis). Authors showed that the addition of dried fruits reduced the glycemic index, with particular significance observed in *thepla* with 9% of papaya peels. This effect was attributed to the presence of soluble and insoluble fibres, altering the gastric fluid viscosity and delaying gastric emptying and inhibiting enzyme-starch binding. Conversely, flatbreads enriched with green vegetables demonstrated increased levels of *in vitro* digestible starch (Bhavya & Prakash, 2021). Therefore, it is not clear the impact of those vegetable or fruit powders as bakery ingredients and their effect on starch hydrolysis.

Because of that, the objective of this study was to develop innovative and healthy flatbreads through the inclusion of different vegetable powders: fatty fruits (black and green olives), citric fruits (orange peel and lemon), berry fruits (tomato), roots (beetroot and carrot), bulbs (onion), inflorescence (artichoke), green leaves (spinach and chard) and cabbages (kale and pak choi), and analyse their technology and nutritional properties, highlighting their effect on carbohydrate digestion in wheat flatbreads.

Materials and methods

Materials

Wheat flour (14.75% moisture, 0.59% ash, 1.83% protein, 1.25% fat, 2.99% total fibre) was purchased from Harinera La Meta S.A (Lleida, Spain). Black and green olives pastes, and onion and lemon powders were provided by Vegenat S.A (Badajoz, Spain). Spinach, artichoke, pak choi, kale and chard powders were from AgroSingularity (Murcia, Spain). Tomato, carrot and beetroot powders were obtained from Ingredíssimo (Barcelona, Spain). The orange powder was in-house prepared from dried orange peel (Gasparre *et al.*, 2024). Dried yeast was provided by Lesaffre (Marcq-en-Baroeul, France). Salt was acquired in the local market.

Physicochemical characteristics of vegetable powders

Proximate composition of vegetable powders was evaluated according to standard methods (ISO): moisture (ISO 712:2009), protein (ISO 16634-2:2016), ash (ISO 2171:2007) and total fat (ISO 11085:2015). For dietary fibre content, the AACC (1999) International method (32–07) was used.

The colour of vegetable powders was measured by chroma meter CR-400 (Konica Minolta, Japan), using the CIEL L^* a^* b^* scale with D65 illumination and a 0° viewing angle geometry, where L^* shows lightness, a^* indicates hue on a green (−) to red (+) axis, and b^* means hue on a blue (−) to yellow (+) axis. In addition, the cylindrical coordinates: hue angle (colour tone) eqn (1) and chroma (colour purity) eqn (2), were calculated by the following equations:

$$Hue = \arctan\left(\frac{b^*}{a^*}\right) \quad (1)$$

$$C^*_{ab} = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

Their particle size was measured using a Mastersizer equipment (Scirocco 2000; Malvern Instruments Ltd., Worcestershire, UK). The parameters defined were d (0.1), d (0.5) and d (0.9), which represented 10%, 50% and 90% of the particles are in that size, respectively. Besides, volume-weighted mean diameter d (4,3) was calculated.

Breadmaking process to obtain flatbreads containing vegetable powders

The single-layer flatbread recipe was formulated with wheat flour W-200 (100%), water (52.5%), salt (1.5%), dry yeast (1%) and vegetable powder (2%) flour-based. The breadmaking process consisted of a two-phase mixing procedure using Robot Coupe RM8 with the spiral mixer (Robot Coupe, Vincenne, France). The first phase without salt was set up at a lower speed (100 rpm) for 3 min, and the second phase with salt at a higher speed (200 rpm) for 4 min. After the mixing phases, the dough rested at room temperature for 15 min, before dividing into 150 g pieces. Next was the fermentation for 50 min at 25 °C, where the proofing volume increase was recorded to select the optimum fermentation time. Following fermentation, the dough was sheeted to a 4 mm-thickness for a single layer flatbread and pierced with a dough docker roller to prevent oven rising. Finally, the baking was at 300 °C for 2 min each side, using a deck oven (BAUUMAN TECH, S.L., Valencia, Spain) and then cooled down at room temperature.

Physicochemical properties of vegetable flatbreads

Flatbread chemical composition was estimated using standard methods as previously mentioned for the vegetable powders. Colour parameters were the same as described for vegetable powders, but the total colour difference (ΔE^*) in flatbread was determined with the following eqn (3):

$$\Delta E^* = \left((L_{r^*} - L_{i^*})^2 + (a_{r^*} - a_{i^*})^2 + (b_{r^*} - b_{i^*})^2 \right)^{1/2} \quad (3)$$

where L_{r^*}, a_{r^*}, b_{r^*} were colour parameters of flatbread without vegetable, and L_{i^*}, a_{i^*}, b_{i^*} were colour parameters of FB including vegetable powders.

The center of the FB was cut out obtaining 4 cm diameter portions and then texture was determined using a Texture Analyzer TA-XT2i (Stable Micro Systems, Surrey, UK) following a TPA test with a double compression (up to 50%) with a 50 mm aluminium probe. The parameters recorded were hardness (N), springiness, cohesiveness, chewiness (N) and resilience.

In vitro starch hydrolysis of flatbreads

Flatbread starch hydrolysis was analysed based on the method described by Santamaria *et al.* (2022). Briefly, the dry and crushed bread (200 mg) was mixed with 4 mL of 0.1 M sodium maleate buffer (pH 6.9) containing porcine pancreatic α-amylase (0.9 U/mL) and incubated at 37 °C for 3 h in a shaker incubator SKI 4 (ARGO Lab, Carpi, Italy). After 24 h of hydrolysis, the remaining starch was solubilised with 2 mL of 1.7 M NaOH and hydrolysed with amyloglucosidase (143 U/mL) for 30 min at 50 °C. The glucose release during the incubation and after 24 h were quantified by glucose oxidase-peroxidase (GOPOD) kit and measured at an absorbance of 510 nm in a microplate reader (Epoch Biotek Instruments, Winooski, VT, USA). Starch was calculated as glucose (mg) × 0.9. Parameters obtained were rapidly digestible starch (RDS) corresponding to the fraction of total starch hydrolysed within 20 min of incubation; slowly digestible starch (SDS) hydrolysed within 20 and 120 min; total digestible starch (DS) after 24 h hydrolysis and the remnant one named resistant starch (RS). Additionally, the kinetic parameters of starch hydrolysis were obtained using a first-order eqn (4) defined by Goñi *et al.* (1997):

$$C = C_\infty \left(1 - e^{-kt}\right) \quad (4)$$

where C was the concentration (g/100 g of FB) at t time (min) of starch hydrolysis, C_∞ was the maximum hydrolysis (g/100 g of FB), k was the kinetic constant (min^{-1}) and t was the selected time (min). Furthermore, the initial reaction rate (k_0) (%*min^{-1}) was calculated by the eqn (5) follow Kan *et al.* (2020) study.

$$\textit{Initial reaction rate} = (C_{10} - C_0)/10 \quad (5)$$

where C_{10} and C_0 were defined as the percentage of starch hydrolysed at 10 and 0 min, respectively and the time selected for the calculation of initial reaction rate was 10 min.

Statistical analysis

All the experimental analysis has been carried out at least in triplicate. Two different batches were carried out for obtaining the breads. Experimental results were processed through one-wat analysis of variance (ANOVA), using OriginPro 9.9.5.167 (OriginLab Corporation, Northampton, EE. UU). Mean values are presented in tables. Fisher's least significant differences test (LSD) was used and differences of $P < 0.05$ were considered significant. Principal component analysis (PCA) was used to discriminate among FB containing vegetables.

Results and discussion

Vegetable powder physicochemical composition

A range of vegetable powders from different origin was selected including, fatty fruits (black and green olives), citric fruits (orange peel and lemon), berry fruits (tomato), roots (beetroot and carrot), bulbs (onion), inflorescence (artichoke), green leaves (spinach and chard) and cabbages (kale and pak choi). Proximate composition (Table 1a), colour and particle size distribution (Table 1b) were evaluated. Statistically significant differences ($P < 0.05$) were observed among their composition: moisture, protein, ash, fat and dietary fibre. The moisture content of the commercial vegetable powders ranged from 1.80% in carrot to 13.62% in tomato powder. Green leaves and cabbage powders showed higher protein (25.33%–32.90%) and mineral (12.89%–22.07%) content. Comparable results in terms of protein (24.85%) and mineral (19.22%) content were reported for dry chard (Alsuhaibani & Alshawi, 2022); and similar results in protein (28.05%) and ash (14.66%) content were found for spinach powder (Junejo *et al.*, 2021). Citric, carrot and fatty fruits had the lowest content of proteins (5.28%–

Table 1a Chemical composition (g/100 g, d.w) of different vegetable powders

Vegetable powder		Moisture	Protein	Ash	Fat	Total dietary fibre	Insoluble dietary fibre
Fatty fruits	Black Olives	4.25 ± 0.07[h]	5.28 ± 0.07[j]	4.68 ± 0.44[g]	52.83 ± 1.29[b]	22.09 ± 0.70[f]	N.D
Fatty fruits	Green Olives	2.29 ± 0.13[i]	6.83 ± 0.28[g]	8.30 ± 0.82[e]	61.73 ± 1.79[a]	27.01 ± 2.43[e]	12.19 ± 0.29[i]
Citric fruits	Orange	9.51 ± 0.40[b]	5.98 ± 0.02[i]	2.23 ± 0.03[j]	1.25 ± 0.02[fg]	40.16 ± 0.30[bc]	31.02 ± 0.30[e]
Citric fruits	Lemon	4.59 ± 0.01[h]	6.44 ± 0.08[h]	3.15 ± 0.11[i]	2.32 ± 0.02[ef]	39.68 ± 2.59[bc]	18.26 ± 2.81[g]
Berry fruits	Tomato	13.62 ± 0.12[a]	13.93 ± 0.06[d]	7.03 ± 0.16[f]	0.46 ± 0.02[g]	9.33 ± 0.01[h]	7.85 ± 0.86[j]
Roots	Carrot	1.80 ± 0.01[j]	6.53 ± 0.01[gh]	4.47 ± 0.03[gh]	0.05 ± 0.00[g]	4.69 ± 0.56[i]	N.D
Roots	Beetroot	4.52 ± 0.07[h]	11.32 ± 0.07[f]	4.66 ± 0.09[g]	0.50 ± 0.01[g]	20.99 ± 1.80[f]	15.57 ± 1.13[h]
Bulbs	Onion	4.64 ± 0.05[h]	12.46 ± 0.12[e]	3.79 ± 0.01[hi]	0.89 ± 0.04[g]	15.74 ± 0.61[g]	6.97 ± 1.26[k]
Inflorescence	Artichoke	8.40 ± 0.04[d]	13.62 ± 0.15[d]	4.45 ± 0.11[g]	2.87 ± 0.00[e]	63.27 ± 0.23[a]	46.85 ± 0.29[a]
Green leaves	Spinach	5.98 ± 0.13[g]	32.90 ± 0.37[a]	22.07 ± 0.32[a]	5.49 ± 0.20[cd]	40.52 ± 0.79[bc]	39.73 ± 2.14[b]
Green leaves	Chard	7.28 ± 0.16[f]	25.33 ± 0.00[c]	19.86 ± 0.78[b]	4.36 ± 0.04[d]	38.39 ± 1.18[c]	33.38 ± 0.24[d]
Cabbages	Kale	7.84 ± 0.08[e]	27.83 ± 0.23[b]	12.89 ± 0.11[d]	6.14 ± 0.01[c]	41.15 ± 0.13[b]	35.67 ± 0.23[c]
Cabbages	Pak Choi	8.92 ± 0.06[c]	27.69 ± 0.19[b]	15.95 ± 0.25[c]	2.62 ± 0.14[e]	35.59 ± 0.13[d]	29.67 ± 0.18[f]
P-value		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Means with different letters within a column were significantly different ($P < 0.05$). N.D: not detected.

Table 1b Colour and particle size parameters of vegetable powders

Vegetable powder		L^*	a^*	b^*	Hue angle (°)	Chroma	*d* (4,3)
Fatty fruits	Black Olives	21.19 ± 0.01[m]	1.28 ± 0.01[g]	−2.24 ± 0.03[m]	299.65 ± 0.17[a]	2.58 ± 0.03[m]	N.D
Fatty fruits	Green Olives	29.78 ± 0.08[l]	2.61 ± 0.01[e]	11.96 ± 0.02[k]	77.68 ± 0.04[i]	12.24 ± 0.02[l]	N.D
Citric fruits	Orange	75.35 ± 0.01[c]	2.73 ± 0.01[d]	52.47 ± 0.01[a]	87.03 ± 0.01[g]	52.54 ± 0.01[b]	244.77 ± 5.89[b]
Citric fruits	Lemon	85.14 ± 0.02[b]	−1.51 ± 0.01[i]	25.32 ± 0.02[d]	93.41 ± 0.03[f]	25.36 ± 0.02[f]	96.99 ± 1.03[g]
Berry fruits	Tomato	46.57 ± 0.01[i]	26.90 ± 0.01[b]	32.17 ± 0.04[c]	50.09 ± 0.03[k]	41.93 ± 0.02[c]	243.71 ± 5.26[c]
Roots	Carrot	66.82 ± 0.05[d]	22.76 ± 0.14[c]	51.27 ± 0.06[b]	66.06 ± 0.11[j]	56.09 ± 0.11[a]	64.96 ± 1.33[j]
Roots	Beetroot	33.94 ± 0.01[k]	36.63 ± 0.03[a]	7.32 ± 0.00[l]	11.30 ± 0.01[l]	37.35 ± 0.03[d]	90.38 ± 0.36[h]
Bulbs	Onion	85.21 ± 0.01[a]	−2.02 ± 0.01[k]	17.63 ± 0.01[j]	96.52 ± 0.02[d]	17.74 ± 0.01[k]	80.79 ± 0.10[i]
Inflorescence	Artichoke	59.16 ± 0.02[e]	−1.76 ± 0.02[j]	22.48 ± 0.02[h]	94.47 ± 0.06[e]	22.54 ± 0.02[i]	231.72 ± 8.61[d]
Green leaves	Spinach	51.84 ± 0.01[g]	−12.29 ± 0.01[m]	24.40 ± 0.02[e]	116.74 ± 0.01[b]	27.32 ± 0.03[e]	56.28 ± 1.94[k]
Green leaves	Chard	42.38 ± 0.04[j]	−1.10 ± 0.02[h]	17.88 ± 0.01[i]	93.50 ± 0.06[f]	17.91 ± 0.02[j]	305.15 ± 6.64[a]
Cabbages	Kale	49.26 ± 0.00[h]	−4.21 ± 0.01[l]	23.13 ± 0.02[f]	100.32 ± 0.02[c]	23.51 ± 0.02[g]	128.77 ± 2.64[f]
Cabbages	Pak Choi	52.01 ± 0.01[f]	1.98 ± 0.04[f]	22.57 ± 0.04[g]	85.00 ± 0.10[h]	22.66 ± 0.04[h]	195.54 ± 2.79[e]
P-value		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Means with different letters within a column were significantly different ($P < 0.05$). N.D: not determined.

6.83%). Likewise, lemon and orange powders presented low amount of ash content (2.23%–3.15%). As expected, fatty fruits had the highest fat content, and artichoke excelled in fibre (63.27%). Values were in the same range as previous findings for lyophilised artichoke (17.9% of proteins and 55% of dietary fibre) (Frutos *et al.*, 2008). Powders derived from citric fruits, green leaves and cabbages exhibited significantly elevated levels of total dietary fibre, in contrast to carrot, tomato and onion. Orange peel chemical composition agrees with previously reported results (Han *et al.*, 2021), although they differed from those reported for *Citrus maxima* peel (Ani & Abel, 2018). Those differences might be attributed to different orange varieties or changes during their production.

The colour attributes of the vegetable powders exhibited statistically significant differences ($P < 0.05$) (Table 1b). High brightness (L^*) was observed for onion, orange and lemon, while beetroot and olives showed the opposite. As expected, beetroot, tomato and carrot showed reddish tones ($+a^*$), and greenish ($-a^*$) was characteristic for green leaves, specifically spinach and kale powders. Fernandez-Pan *et al.* (2023) found similar colour values (L^*: 40.50; a^*: 34.98; b^*: 41.09) in a tomato by-product. In general, the vegetable powders showed a yellowish tone ($+b^*$), higher in orange and carrot, but a blue tone ($-b^*$) in black olives powder. Moreover, the colour tone, represented by hue-angle, indicated that powders were generally yellowish (~90°), except for beetroot that had a reddish hue (~ 0°), spinach and kale a greenish hue (~180°) and black olives with a dark hue (300°). Chroma values, indicative of colour purity, were higher for carrot, orange and tomato powders, related to greater intensity of the yellow component. Conversely, black olives showed a dull purity of colour.

In vegetable powders, particle size distribution is not a commonly examined parameter, perhaps due to its processing variability. In this study, it was analysed owing to its impact on technological properties of bread and further digestion (Fig S1). Chard, orange and tomato powders had higher volume-weighted mean diameter *d* (4, 3) than onion, carrot and spinach powders (Table 1b).

Flatbreads containing vegetable powders

Vegetable powders provide an alternative way to obtain innovative flatbreads (Fig. 1), besides leading to significantly ($P < 0.05$) different composition (Table 2). The moisture content of flatbreads ranged from 33.34% in kale FB to 35.79% in tomato FB. Since the same amount of water was used in the recipe, this could be associated with the moisture content present in the raw materials, specifically, in tomato powder (Table 1a). FB formulated with green leaves, spinach and chard, showed higher content in protein (12.49%–12.50%) and ash (1.42%–1.30%), while pak choi and tomato only increased the protein content. As expected, the fat content in FB increased with the addition of olives, followed by tomato. Ranawana *et al.* (2016) observed similar trend when 10% wheat flour was replaced by tomato or broccoli. Moreover, flatbread with spinach presented reduced fat content. Okpala & Akpu (2013) observed a decrease in lipid and protein content in wheat breads containing orange peel (3%, 6%, 9%), but in the present study that reduction was not statistically significant. Regarding fibre content, following nutritional claims outlined in Regulation (CE) No. 1924/2006, those enriched flatbreads would be categorised as 'high fibre' (6 g of fibre per 100 g), except for lemon, spinach and kale flatbreads, which could be labelled as a 'source of fibre' (3 g of fibre per 100 g). Compared to the control, the incorporation of artichoke into flatbread significantly increases the total (9.33%) (Table 2), which might be attributed to its inulin content (Frutos *et al.*, 2008). Nevertheless, the fibre content in the breads was not correlated with the fibre amount quantified in the vegetable powder. Specifically, onion FB exhibited elevated total and insoluble fibre, despite the lower amount presented in the powder. A plausible explanation would be that interactions with other baking ingredients or the impact of processing could promote the formation of biopolymers quantified in the fibre procedure. In the case of carrot bread, a minimal increase in fibre and protein content was obtained, whereas a reduction in fat content was observed. Onwurafor *et al.* (2022) formulated a bread by mixing wheat-sorghum flour, mung bean malt and carrot flour and correlated the protein decrease and fibre increase with the composition of mung bean malt and carrot.

A great impact was observed on the FB colour parameters (Table 3; Fig. 1). Although usually the colour in breads is attributed to the colour of the raw materials, some variations were observed after the baking compared to the colour of the vegetable powders (Table 1b). Respect to control flatbread, lightness (L^*) remained high in onion, lemon and orange, and low in beetroot, as discussed above for the vegetable powders. Similar L^* was obtained for wheat bread with 2.5% white onion (Michalak-Majewska *et al.*, 2017). The a^* value in FB showed no change compared to those obtained for the vegetable powders. Overall, flatbreads showed a yellowish tone ($+b^*$). Tomato flatbread showed similar colour values to those obtained by Mehta *et al.* (2018) and Fernandez-Pan *et al.* (2023). Flatbreads exhibited a yellowish tone (~90°), except beetroot flatbread that had a reddish hue (23.66°) and spinach flatbread with a yellow-green hue (106.30°). The spinach changes may be attributed to its pigments like beta-carotene and xanthophyll, showing a yellow hue or chlorophyll, which contributes to the green colour (Junejo *et al.*, 2021). The total colour difference (ΔE^*) calculated on the basis of control flatbread, confirmed a drastic colour change in beetroot, spinach and carrot flatbreads, which could be related to the pigment content of these vegetable powders. Sobota *et al.* (2020) found significant correlations between vegetable pigments from beetroot, carrot or kale powders, and the tagliatelle formulated with durum semolina substituted (2%, 4%, 6%, 8%) of beetroot, carrot and kale.

Flatbreads showed statistically significant differences ($P < 0.05$) in their textural parameters according to the vegetable powder added (Table 4). A varied impact was observed on the bread hardness. Spinach and artichoke FB displayed a hardness increased, although the impact was not statistically significant. However, this trend was also observed by Junejo *et al.* (2021) when adding spinach powder to wheat bread; or in wheat chapati unleavened flatbread with spinach powder (Khan *et al.*, 2015). Ebrahimi *et al.* (2021) related the reduction in springiness promoted by spinach powder to the presence of high protein, dietary fibre, calcium and iron in the spinach, that resulted in a hard dough and subsequently in lower springiness. Although not statistically significant, spinach FB springiness decreased compared to control FB. Therefore, the hardness and chewiness increased in artichoke FB, without statistically significant differences with control FB, might be related to its higher fibre quantity (Table 2) (Frutos *et al.*, 2008). Otherwise, onion reduced chewiness. Siddiqui *et al.* (2022) observed similar results in chapattis textural properties formulated with whole wheat flour and onion peel powder (1%,

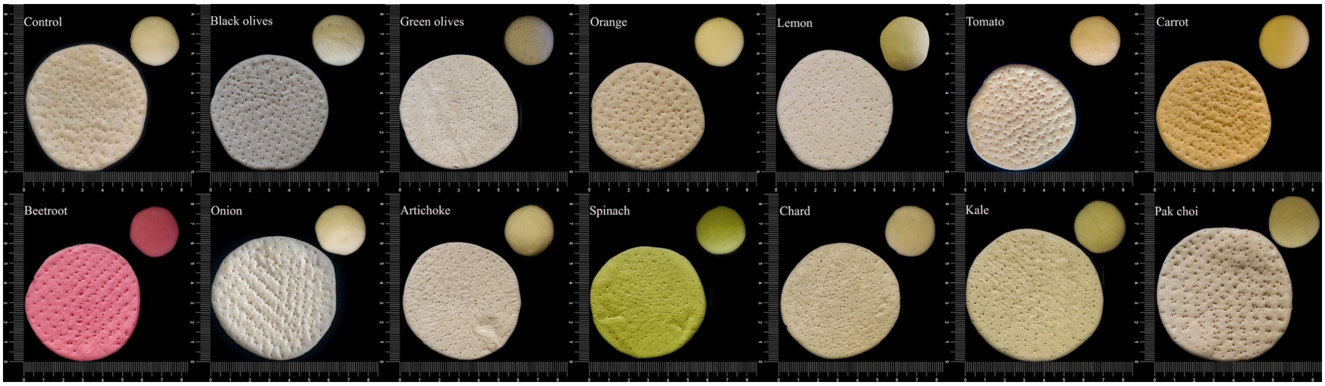

Figure 1 Captured images of doughs and flatbreads containing vegetable powders.

Table 2 Chemical composition (g/100 g, w.b) of flatbreads containing vegetable powders

Flatbread	Moisture	Protein	Ash	Fat	Total dietary fibre	Insoluble dietary fibre
Control	35.50 ± 0.69^{abc}	11.93 ± 0.05^{gh}	1.01 ± 0.04^{b}	0.33 ± 0.01^{cde}	6.50 ± 1.16^{def}	5.74 ± 2.51^{e}
Black Olives	34.79 ± 0.27^{abcd}	12.14 ± 0.01^{cdefg}	0.92 ± 0.05^{b}	0.64 ± 0.04^{a}	7.87 ± 0.25^{bcd}	4.08 ± 0.97^{i}
Green Olives	33.98 ± 0.27^{de}	12.01 ± 0.16^{fgh}	0.96 ± 0.08^{b}	0.63 ± 0.02^{a}	7.55 ± 1.08^{cd}	3.60 ± 0.12^{j}
Orange	34.67 ± 0.59^{bcd}	12.04 ± 0.04^{efgh}	0.94 ± 0.05^{b}	0.27 ± 0.08^{ef}	6.27 ± 1.07^{def}	6.10 ± 0.13^{d}
Lemon	34.81 ± 0.95^{abcd}	11.96 ± 0.01^{fgh}	1.00 ± 0.02^{b}	0.31 ± 0.01^{def}	4.86 ± 1.97^{ef}	N.D
Tomato	35.79 ± 0.47^{a}	12.37 ± 0.09^{ab}	1.00 ± 0.01^{b}	0.44 ± 0.05^{b}	9.39 ± 1.39^{abc}	6.95 ± 2.84^{b}
Carrot	35.64 ± 0.40^{ab}	12.24 ± 0.17^{bcde}	1.01 ± 0.06^{b}	0.27 ± 0.04^{ef}	6.99 ± 0.62^{cde}	5.34 ± 1.05^{f}
Beetroot	34.19 ± 0.20^{de}	12.16 ± 0.01^{bcdef}	1.00 ± 0.10^{b}	0.38 ± 0.05^{bcd}	7.89 ± 1.18^{bcd}	5.25 ± 0.31^{g}
Onion	34.60 ± 0.07^{bcd}	11.83 ± 0.05^{h}	0.98 ± 0.07^{b}	0.29 ± 0.02^{def}	11.18 ± 2.22^{a}	9.96 ± 1.68^{a}
Artichoke	34.52 ± 0.80^{cd}	12.26 ± 0.08^{bcd}	0.98 ± 0.05^{b}	0.33 ± 0.09^{cde}	9.33 ± 0.56^{abc}	6.19 ± 0.27^{c}
Spinach	34.22 ± 0.23^{de}	12.49 ± 0.07^{a}	1.42 ± 0.25^{a}	0.22 ± 0.02^{f}	5.73 ± 1.44^{def}	2.68 ± 0.69^{k}
Chard	34.68 ± 0.20^{bcd}	12.50 ± 0.06^{a}	1.30 ± 0.01^{a}	0.30 ± 0.04^{def}	10.73 ± 0.87^{a}	1.64 ± 0.00^{m}
Kale	33.34 ± 0.70^{e}	12.05 ± 0.21^{defg}	0.95 ± 0.03^{b}	0.41 ± 0.01^{bc}	4.24 ± 0.00^{f}	1.07 ± 0.11^{l}
Pak Choi	34.06 ± 0.41^{de}	12.35 ± 0.10^{ab}	0.99 ± 0.05^{b}	0.28 ± 0.03^{ef}	10.20 ± 0.06^{ab}	4.73 ± 0.55^{h}
P-value	0.0136	0.0001	0.0012	0.0000	0.0005	0.0024

Means with different letters within a column indicates significant differences ($P < 0.05$). N.D: not detected.

Table 3 Colour parameters of flatbreads with vegetable powders

Flatbread	*L**	*a**	*b**	Hue Angle (°)	Chroma	Δ*E**
Control	69.82 ± 1.25^{b}	−0.47 ± 0.22^{f}	22.22 ± 0.31^{g}	91.20 ± 0.58^{f}	22.23 ± 0.30^{g}	–
Black Olives	61.07 ± 1.65^{d}	1.63 ± 0.19^{d}	17.69 ± 0.62^{h}	84.73 ± 0.57^{i}	17.77 ± 0.63^{h}	11.03 ± 0.43^{g}
Green Olives	70.34 ± 1.55^{b}	−0.60 ± 0.13^{fg}	24.64 ± 0.72^{e}	91.40 ± 0.32^{ef}	24.65 ± 0.71^{e}	2.87 ± 0.55^{m}
Orange	73.77 ± 1.31^{a}	−1.77 ± 0.11^{h}	29.55 ± 0.57^{c}	93.44 ± 0.22^{c}	29.60 ± 0.57^{c}	8.50 ± 0.75^{i}
Lemon	74.63 ± 1.41^{a}	−0.56 ± 0.52^{fg}	23.85 ± 0.30^{f}	91.90 ± 0.27^{de}	23.86 ± 0.30^{f}	5.67 ± 0.42^{j}
Tomato	65.63 ± 1.57^{c}	8.48 ± 0.29^{b}	34.23 ± 0.39^{b}	76.08 ± 0.53^{j}	35.27 ± 0.36^{b}	15.62 ± 0.36^{d}
Carrot	70.30 ± 1.55^{b}	2.16 ± 0.59^{c}	43.98 ± 0.78^{a}	87.19 ± 0.72^{h}	44.03 ± 0.81^{a}	21.97 ± 0.81^{c}
Beetroot	44.02 ± 0.36^{h}	32.96 ± 0.28^{a}	14.20 ± 0.48^{i}	23.66 ± 0.60^{k}	35.68 ± 0.42^{b}	43.09 ± 0.31^{a}
Onion	73.19 ± 1.73^{a}	−0.73 ± 0.09^{fg}	22.49 ± 0.40^{g}	91.85 ± 0.26^{de}	22.50 ± 0.40^{g}	4.63 ± 0.10^{k}
Artichoke	66.11 ± 1.94^{c}	−0.91 ± 0.24^{g}	23.91 ± 0.49^{f}	92.18 ± 0.60^{d}	23.93 ± 0.49^{f}	3.68 ± 1.12^{l}
Spinach	52.58 ± 0.84^{g}	−9.96 ± 0.29^{j}	34.07 ± 0.53^{b}	106.30 ± 0.40^{a}	35.50 ± 0.55^{b}	22.98 ± 0.66^{b}
Chard	56.05 ± 1.72^{f}	−1.44 ± 0.10^{h}	24.05 ± 0.52^{ef}	93.43 ± 0.19^{c}	24.09 ± 0.53^{ef}	14.64 ± 0.52^{e}
Kale	59.08 ± 2.08^{e}	−3.52 ± 0.14^{i}	27.98 ± 0.35^{d}	97.18 ± 0.29^{b}	28.20 ± 0.35^{d}	11.76 ± 0.44^{f}
Pak Choi	61.87 ± 1.69^{d}	1.02 ± 0.23^{e}	29.03 ± 0.55^{c}	87.99 ± 0.47^{g}	29.05 ± 0.54^{c}	10.66 ± 1.02^{h}
P-value	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000

Means with different letters within a column indicates significant differences ($P < 0.05$).

Table 4 Textural parameters of vegetable flatbreads

Flatbread	Hardness (N)	Springiness	Cohesiveness	Chewiness (N)	Resilience
Control	5.29 ± 0.61[abc]	0.978 ± 0.014[abc]	0.800 ± 0.012[bc]	4.16 ± 0.47[abcd]	0.312 ± 0.010[cd]
Black Olives	5.42 ± 0.59[abc]	0.982 ± 0.003[ab]	0.782 ± 0.010[de]	4.16 ± 0.50[abc]	0.320 ± 0.010[bc]
Green Olives	4.21 ± 0.41[de]	0.983 ± 0.007[a]	0.808 ± 0.007[ab]	3.53 ± 0.45[cdef]	0.339 ± 0.011[a]
Orange	5.20 ± 0.36[abc]	0.956 ± 0.017[de]	0.761 ± 0.017[f]	3.78 ± 0.28[bcde]	0.280 ± 0.014[gh]
Lemon	4.92 ± 0.46[bcd]	0.957 ± 0.007[de]	0.744 ± 0.010[f]	3.51 ± 0.34[def]	0.288 ± 0.009[fg]
Tomato	4.06 ± 0.53[e]	0.951 ± 0.007[e]	0.761 ± 0.010[f]	2.94 ± 0.41[f]	0.272 ± 0.007[h]
Carrot	5.12 ± 0.80[abc]	0.966 ± 0.011[bcde]	0.798 ± 0.012[bcde]	3.93 ± 0.57[abcd]	0.301 ± 0.005[def]
Beetroot	5.18 ± 0.43[abc]	0.967 ± 0.004[abcde]	0.786 ± 0.021[cde]	3.94 ± 0.37[abcd]	0.296 ± 0.019[ef]
Onion	4.78 ± 0.10[cd]	0.963 ± 0.023[cde]	0.798 ± 0.014[bcd]	3.18 ± 0.87[ef]	0.313 ± 0.015[cd]
Artichoke	5.53 ± 0.48[ab]	0.966 ± 0.013[bcde]	0.807 ± 0.015[ab]	4.31 ± 0.37[ab]	0.319 ± 0.009[bc]
Spinach	5.91 ± 0.53[a]	0.968 ± 0.017[abcd]	0.791 ± 0.008[bcde]	4.53 ± 0.39[a]	0.304 ± 0.005[de]
Chard	5.37 ± 0.38[abc]	0.970 ± 0.021[abcd]	0.818 ± 0.022[a]	4.26 ± 0.31[ab]	0.331 ± 0.019[ab]
Kale	5.02 ± 1.10[bc]	0.978 ± 0.007[abc]	0.804 ± 0.006[abc]	3.95 ± 0.88[abcd]	0.323 ± 0.006[bc]
Pak Choi	5.25 ± 0.55[abc]	0.963 ± 0.011[cde]	0.781 ± 0.015[e]	3.95 ± 0.46[abcd]	0.300 ± 0.012[def]
P-value	0.0005	0.0036	0.0000	0.0003	0.0000

Values followed by different letters within a column denote significant differences ($P < 0.05$).

2%, 3%). Likely, the fibre content of that bread hindered the gluten network. On the other hand, high fat content, like the one provided by olives incorporation enhanced the springiness in the flatbread (Table 2). Tomato powder decreased all textural parameters, especially the flatbread hardness respect to control FB, which might be related to the type of hydrocolloid/fibre of that powder (Mehta *et al*., 2018).

The starch digestion curves for vegetable flatbreads during 3 h of *in vitro* hydrolysis were displayed in Fig. 2. The performance of starch hydrolysis in flatbreads was altered with the addition of different vegetable powders. The analysis and data fit of *in vitro* digestion parameters showed statistically significant differences ($P < 0.05$), except for the kinetic constant (Table 5). The incorporation of vegetables in flatbreads changed starch digestion performance, affecting the glycemic response. The inclusion of orange peel had a pronounced effect on reducing the SDS fraction and the maximum concentration and increasing the RS, possibly associated with the total fibre content of the orange powder, as indicated above in Table 1a, either the presence of total polyphenols (40.32 mg/g reported by Han *et al.* (2021)), or the antioxidant activity (tannins, saponins and alkaloids) obtained by Okpala & Akpu (2013). In addition, artichoke flatbread presented a non-significant decrease in the RDS and initial rate, which could be related to its high dietary fibre content (Table 1a), particularly attributable to the presence of inulin (El-Hadidy *et al*., 2022). Furthermore, onion flatbread presented lower SDS, and C_∞ and higher RS, which is in accordance with its high fibre content (Table 1a). Besides, these results might be linked to the onion bioactive compounds, especially quercetin and quercetin derivates (Michalak-Majewska *et al*., 2017). This correlation has been also reported in whole grain chapatti containing onion peel powder, where an increase in total phenolic and flavonoid content was observed (Siddiqui *et al*., 2022). Likewise, the initial rate was diminished in the case of tomato flatbread, leading to a reduction in the RDS and the C_∞, while increasing the content of resistant starch. These results might relate to the interaction of starch with total dietary fibre (Table 2) and the antioxidant activity (lycopene and carotenoids) described by Mehta *et al.* (2018) in bread with fresh tomato pomace. Nonetheless, the most noticeable and impactful effect was observed with the addition of lemon powder. Lemon flatbread had a significant impact on the starch digestion, showing the lowest hydrolysis, resulting in a decrease of RDS, SDS and C_∞, while increasing RS. Recently, Freitas *et al.* (2021) investigated bread prepared by substituting water with lemon juice, observing reduced mean blood glucose concentration peak. The results were associated with the acidity of foods and meals, which attenuate the activity of salivary α-amylase enzyme during starch digestion, due to its inactivation caused by a lower pH.

It was clear that vegetable powders resulted in significant impact on bread quality even with 2% addition and a variety of effects were observed depending on the specific powder. Nevertheless, to help assessing the global impact of those powders on breadmaking a principal component analysis (PCA) was carried out with all the parameters analysed (Fig. 3). Two components were able to describe the variability of the samples, component 1 and 2 explained 36.88% and 15.93% of the variability, respectively. The most divergent vegetable powders were lemon, spinach and green olives, which were more distant in the spatial location. The high RS obtained in lemon FB, the protein and

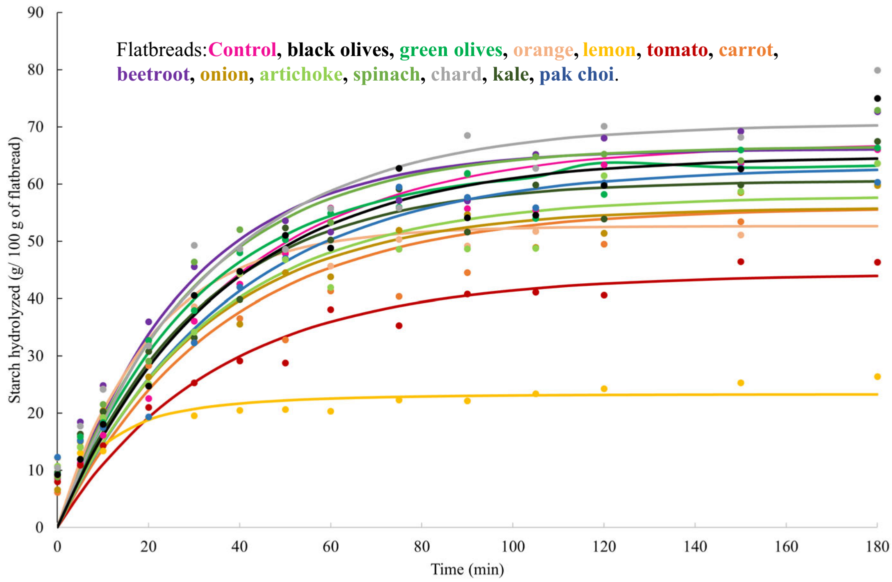

Figure 2 Effect of vegetable powders on flatbread enzymatic digestion. Experimental (•) and modelled (–) data.

Table 5 Parameters of *in vitro* vegetable flatbreads hydrolysis: rapidly digestible starch (RDS), slowly digestible starch (SDS), digestible starch (DS), resistant starch (RS), kinetic constant (k), maximum concentration (C_∞) and initial reaction rate (k_0)

Flatbread	RDS (g/100 g)	SDS (g/100 g)	DS (g/100 g)	RS (g/100 g)	k (min^{-1})	C_∞	k_0 (%*min^{-1})
Control	28.02 ± 1.67^{abc}	36.49 ± 1.22^{a}	64.03 ± 0.00^{ab}	10.46 ± 0.15^{f}	0.027 ± 0.002^{b}	67.19 ± 0.29^{ab}	1.590 ± 0.110^{cde}
Black Olives	28.00 ± 0.46^{abc}	34.67 ± 2.37^{ab}	64.41 ± 0.15^{ab}	11.12 ± 0.14^{ef}	0.028 ± 0.001^{b}	64.87 ± 3.28^{abcd}	1.597 ± 0.017^{cde}
Green Olives	30.54 ± 1.28^{abc}	33.16 ± 6.52^{ab}	59.04 ± 4.99^{bc}	11.01 ± 0.56^{ef}	0.034 ± 0.007^{ab}	63.42 ± 6.77^{abcde}	1.792 ± 0.143^{abcd}
Orange	32.91 ± 3.06^{ab}	19.61 ± 0.20^{d}	55.33 ± 1.64^{cd}	12.71 ± 0.24^{cd}	0.049 ± 0.003^{ab}	52.67 ± 2.80^{fg}	2.042 ± 0.215^{a}
Lemon	18.78 ± 5.57^{e}	7.05 ± 3.21^{e}	28.10 ± 4.99^{e}	17.91 ± 1.97^{a}	0.057 ± 0.001^{a}	23.27 ± 4.55^{h}	1.653 ± 0.059^{cde}
Tomato	19.21 ± 1.23^{de}	23.38 ± 6.11^{cd}	50.94 ± 0.38^{d}	14.26 ± 0.05^{b}	0.029 ± 0.008^{b}	44.34 ± 6.55^{g}	1.101 ± 0.109^{f}
Carrot	24.02 ± 3.32^{cd}	29.88 ± 1.83^{abc}	55.62 ± 1.79^{cd}	13.72 ± 0.00^{bc}	0.028 ± 0.005^{b}	55.99 ± 0.32^{def}	1.371 ± 0.219^{ef}
Beetroot	33.74 ± 0.07^{a}	31.50 ± 1.85^{ab}	64.89 ± 0.17^{ab}	13.48 ± 0.00^{bc}	0.036 ± 0.002^{ab}	66.17 ± 1.99^{abc}	1.985 ± 0.018^{ab}
Onion	25.77 ± 0.75^{bcd}	28.78 ± 0.45^{bc}	59.22 ± 5.01^{bc}	12.79 ± 0.15^{cd}	0.031 ± 0.001^{b}	55.93 ± 0.11^{ef}	1.486 ± 0.050^{de}
Artichoke	25.94 ± 0.82^{bcd}	30.27 ± 4.07^{ab}	65.43 ± 2.06^{ab}	11.51 ± 0.53^{def}	0.030 ± 0.004^{b}	57.94 ± 4.21^{cdef}	1.490 ± 0.074^{de}
Spinach	32.37 ± 2.61^{ab}	32.97 ± 2.04^{ab}	64.32 ± 2.66^{ab}	11.31 ± 0.00^{ef}	0.033 ± 0.004^{ab}	66.63 ± 0.01^{abc}	1.887 ± 0.182^{abc}
Chard	32.47 ± 5.87^{ab}	36.09 ± 2.78^{a}	63.15 ± 3.00^{ab}	10.20 ± 0.45^{f}	0.030 ± 0.004^{b}	70.61 ± 7.86^{a}	1.830 ± 0.422^{abc}
Kale	28.81 ± 0.74^{abc}	30.55 ± 2.38^{ab}	68.06 ± 6.02^{a}	11.34 ± 0.43^{ef}	0.032 ± 0.001^{ab}	60.63 ± 3.41^{bcdef}	1.671 ± 0.034^{bcd}
Pak Choi	26.04 ± 2.03^{bcd}	34.40 ± 2.12^{ab}	67.39 ± 2.77^{a}	12.05 ± 0.77^{de}	0.027 ± 0.000^{b}	63.01 ± 4.20^{abcde}	1.475 ± 0.118^{de}
P-value	0.0010	0.0000	0.0000	0.0000	0.3799	0.0000	0.0010

Means within the same column followed by different letters indicate significant differences ($P < 0.05$).

ash content of the spinach FB and the fat content of the green olives FB explained those differences. Flatbreads formulated with chard, pak choi, kale, artichoke and beetroot were grouped owing to their positive impact on the starch enzymatic hydrolysis. Conversely, carrot, tomato, onion, orange and lemon flatbreads, reduced the enzymatic digestion of starch. Moreover, onion increased lightness, whereas carrot, tomato and orange flatbreads enhanced the yellowish tone (b^*). Furthermore, in general textural properties like hardness, chewiness, resilience and springiness were higher in FB containing green vegetables, in opposition to lemon, tomato, orange, carrot and onion. The PCA confirmed the effect of vegetable powders on the technology and nutritional flatbread properties, especially regarding starch digestion.

Conclusions

The addition of vegetable powders into flatbreads allowed to obtain innovative bakery products with diverse appearance. However, the inclusion of 2% vegetable powders impacted FB features, their nutritional composition and the starch enzymatic hydrolysis.

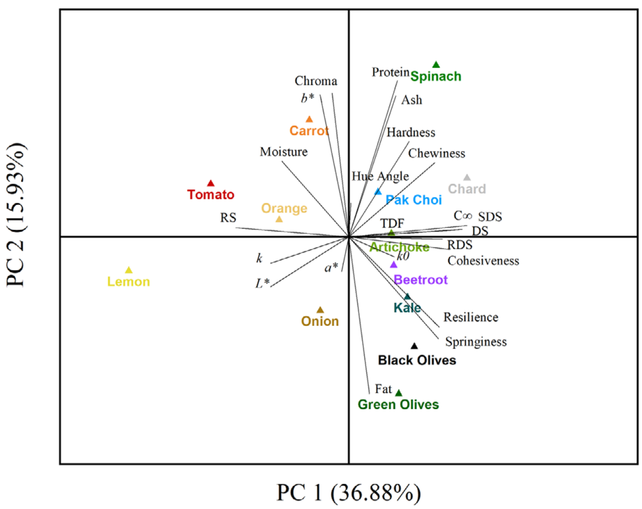

Figure 3 Principal component analysis (PCA) plot of different vegetable flatbreads and related with their technological and nutritional properties.

Vegetable powders presented differences in their physicochemical properties, highlighting the higher proteins, ash and fibre content in green leaves and cabbages powders. However, artichoke powder revealed more total dietary fibre amount. Besides, the presence of natural pigments in vegetable powders resulted in higher total colour difference in flatbreads with beetroot, spinach and carrot. These findings were correlated to their textural properties and starch digestibility. Among vegetable powders, spinach and artichoke enhanced the flatbread hardness, which was reduced in tomato flatbread. Moreover, starch *in vitro* digestion was greatly affected with the addition of lemon, tomato, carrot, orange and onion, particularly due to the increase in RS. Vegetables can serve as natural and healthy ingredient in the production of flatbreads, providing additional nutritional and technological characteristics. Likewise, their impact on the starch hydrolysis opens the possibility to evaluate their addition to control the postprandial response after bread consumption.

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Author contributions

Maria Santamaria: Writing – original draft; investigation; data curation; formal analysis. **Maria Ruiz:** Investigation; methodology. **Raquel Garzon:** Conceptualization; supervision; formal analysis; writing – review and editing. **Cristina M. Rosell:** Conceptualization; investigation; supervision; writing – review and editing; resources; project administration.

Conflicts of interest

The authors have no conflicts of interest to declare.

Ethical guidelines

Ethics approval was not required for this research.

Peer review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ijfs.17441.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Particle size distribution of the vegetable powders determined by laser diffraction using a Mastersizer. Vegetables powders: orange, lemon, tomato, carrot, beetroot, onion, artichoke, spinach, chard, kale, pak choi.

