LWT - Food Science and Technology 199 (2024) 116073

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Evaluation of the technological and compositional features of pancakes fortified with *Acheta domesticus*

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A R T I C L E I N F O

Keywords:
Acheta domesticus
Pancakes fortification
Rheology
Texture analysis

A B S T R A C T

This work focused on the nutritional and technological evaluation of pancakes fortified with increasing *Acheta domesticus* powder (AP) levels. Scientific literature underscores AP's potential as an ingredient in bakery formulations due to its notable fiber and protein content. Thus, we formulated different pancake samples by replacing wheat flour (WF) with 10, 20, and 30% of AP, denoted as AP10, AF 20, and AP30, respectively, alongside a control sample (CP). We evaluated Water Absorption Capacity (WAC) and Water Solubility Index (WSI) on WF, AP, different WF and AP mixes, and batters' rheology. Lastly, we assessed the pancakes' physical, technological, and compositional parameters. The consistency index, flow index, and density increased from CP to AP30. A similar trend was observed for the textural parameter of hardness and chewiness, while cohesiveness slightly decreased. The pancake diameter and height were higher in fortified samples than in CP. A noticeable shift from brighter to darker color was observed from CP to AP30, with an increase in the a* (toward red) and b* parameters (toward blue). AP can represent a valuable ingredient for baked good fortification.

1. Introduction

The world population is estimated to increase by 2050 approximately 9 billion (Grdeń, Kobak, & Sołowiej, 2022), and the food demand will follow this trend (Food and Agriculture Organization of the United Nations, 2021). For this reason, researchers are looking for new protein sources to guarantee protein intake for the entire population with minimal environmental impacts (Guiné, 2020). Moreover, according to the European Green Deal, for the reduction of greenhouse gases and the achievement of climate neutrality, and following the sustainable goals of Agenda 2030, several authors consider the edible insect's food chain a probable and promising frontier as an unconventional or additional animal protein source (Guiné, 2020; Guiné, Correia, Coelho, & Costa, 2021; La Barbera, Verneau, Videbæk, Amato, & Grunert, 2020). The edible insect market is expected to grow at over 47% CAGR between 2023 and 2032, with the most significant increase in North America and Europe (Global Market Insight, 2023). The recent rising interest in insects as a valuable resource for human nutrition is related to their nutritional values, which depend on their diet, cultivation, metamorphic stage, habitat, and processing (Boulos, Tännler, & Nyström, 2020). Recently, the European Commission issued Regulations EU 2022/188 and 2023/5 (European Commission, 2022; European Commission, 2023), authorizing the placing on the market of frozen, dried, and powdered forms of *Acheta domesticus* as a novel food. Nowadays, *A. domesticus* is the most used edible insect due to its availability and standardization of production (Bresciani, Cardone, Jucker, Savoldelli, & Marti, 2022; Van Huis, 2013). It has been shown that the dried and powdered shapes are preferred to whole insects for consumer acceptability, and many studies documented the replacement of wheat flour or semolina with *A. domesticus* powder (AP) at different levels in different foods (Cappelli, Oliva, Bonaccorsi, Lorini, & Cini, 2020). *A. domesticus* is recognized for its high dietary fiber (chitin and chitosan), fatty acids (ω-6 fatty acids and ω-3 fatty acids), vitamins (especially B-complex), minerals, and protein content (Rumpold & Schlüter, 2013b; Van Huis, Rumpold, Maya, & Roos, 2021).

Nevertheless, as a novel food, insect proteins must be characterized

Abbreviations: IP, insect powder; AP, *Acheta domesticus* powder; WF, Wheat flour; CP, control sample; AP10, 10% *Acheta domesticus* powder fortification; AP20, 20% *Acheta domesticus* flour fortification; AP30, 30% *Acheta domesticus* powder fortification; WAC, Water Absorption Capacity; WSI, Water Solubility Index; *n*, flow index; K, consistency index; CAGR, compound annual growth rate; a_W, water activity; PDCAAS, Protein Digestibility Corrected Amino Acid Score.

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https://doi.org/10.1016/j.lwt.2024.116073
Received 29 January 2024; Received in revised form 9 April 2024; Accepted 11 April 2024
Available online 17 April 2024

for quantity and quality to fully understand their potential for human nutrition and use in the food industry (European Commission, 2022). Hence, a comparable evaluation of the protein quality to inform consumers about insects as an alternative protein source to traditional animal foods such as meat and dairy in human diets is necessary. To the best of our knowledge, *A. domesticus* protein digestibility-corrected amino acid score (PDCAAS) is lower at 0,73 compared to other animal proteins (i.e., 1 for milk or egg protein) (Bas & El, 2022). Accurate quantification of insect protein is crucial in determining their nutritional value since not all nitrogen detected in insects originates from proteins. In this sense, the non-digestible nitrogen content, including chitin and proteins linked to the cuticle matrix, might be overestimated using the classical protein determination Kjeldahl method and the incorrect conversion factor of nitrogen in protein determination (Ritvanen, Pastell, Welling, & Raatikainen, 2020). This fact overstates the protein content of insects as it fails to distinguish between easily digested proteins, inaccessible proteins, chitin, and other nitrogen-containing molecules (Malla & Roos, 2023). Moreover, the mineral bioaccessibility needs further investigation (Van Huis et al., 2021). Nevertheless, also considering the previous issues, AP could represent an attractive and suitable ingredient to fortify wheat-based products with low protein content and lacking some micronutrients (Tolve, Bianchi, Lomuscio, Sportiello, & Simonato, 2022). Among the different applications found in the literature can be listed tortillas (Alvarez-Barajas, Perez-Carrillo, & De La Rosa, 2023), corn snacks (Ruszkowska, Tańska, & Kowalczewski, 2022), pasta (Pasini, Cullere, Vegro, Simonato, & Dalle Zotte, 2022), and bread (Kowalski, Mikulec, Mickowska, Skotnicka, & Mazurek, 2022; Osimani et al., 2018). However, the AP addition to sugar-containing products induces the Maillard reaction essential for the cooked products' color, taste, and flavor, which can result in lowering protein availability (Li et al., 2022). To the best of our knowledge, few authors studied the fortification of pancakes with AP, mainly to evaluate their potential acceptability by consumers (Mazurek, Palka, Skotnicka, & Kowalski, 2022). The present study aims to investigate the rheological, technological, and compositional properties of pancakes fortified with 10, 20, and 30% of *A. domesticus* (named AP10, AP20, and AP30, respectively) to assess its use as a possible ingredient in the pancake formulation.

2. Materials and methods

2.1. Pancake ingredients and preparation

Wheat flour (WF) and *Acheta domesticus* powder (AP) were kindly provided by Macinazione Lendinara S.p.A (Verona, Italy) and Italian Cricket Farm S.r.l (Scalenghe, Torino, Italy), respectively. Pasteurized egg whites, sugar, and salt were purchased from local markets. The composition of wheat flour, as reported on the label, was: total carbohydrates 71 g/100 g, fat 1.2 g/100 g, protein 11 g/100 g, and total dietary fiber 2.3 g/100 g.

Wheat flour was mixed with all the other dry ingredients (sugar, salt, and baking powder) and water in a bowl, while the egg whites were whipped in a domestic planetary mixer (KENWOOD company, Chef XL KVL4100S). The planetary was set at medium-low speed for 2 min, and then the speed was raised to the maximum for 7 min until the egg white became consistent. Then, whipped egg white and the dough were mixed to obtain a control sample (CP). Successively, WF was replaced by 10, 20, and 30% of AP to obtain AP10, AP20, and AP30, respectively. Table 1 reports the pancake formulations. Forty mL of batter was dispensed with a commercial pressure syringe (De Buyer, France, REF: 3358.01) and cooked for 6 min (3 min per side) on an electric crêpes' maker (KRAMPOU CSRO4AA-KR, France).

2.2. Proximate composition of pancakes, A. domesticus flour

A. domesticus flour and pancake samples were analyzed for ash (method 942.05), crude lipid (method 954.02), and total soluble and insoluble dietary fiber contents (method 991.43). Crude proteins were analyzed through the Kjeldahl method (method 976.05), and the protein content was measured using 5.09 as a conversion factor (Ritvanen et al., 2020).

2.3. Rheological analysis

The density of the pancake batter was measured by pouring 5 mL into a pre-weighted syringe and weighing it. The rheology of batters was measured with a rheometer DRS500 CP4000 PLUS (Lamy Rheology, France) following the method of Bianchi et al., 2022 with minor adaptation by using MSDIN-11 system. Fifteen mL of batter was poured into the vessel and rested for 1 min to allow relaxation and to reach the constant temperature of 25 °C. The shear stress was a function of the shear rate over the 10–300 s-1 range. The Power Law model (PL) fits the results using the software program Rheotex (Lamy Rheology, France). The PL model is represented in equation (2):

$$\tau = K * \gamma^{n} \tag{2}$$

Where "τ" was shear stress (Pa), "K" was the consistency index (Pa), and "n" was the flow index. All measurements were made in triplicate.

2.4. Water absorption capacity and water solubility index of WF and AP and mixed flours

The hydration levels of all the samples were better defined by the evaluation of water absorption capacity (WAC) and water solubility index (WSI) as described by Alvarez-Barajas et al., 2023; Rainero et al., 2022, respectively, with minor modifications. Briefly, 30 mL of water at 30 °C was added to 3 g of each sample in a 50 mL tube. Then, tubes were stirred for 30 min and centrifuged at 3000 *g* for 10 min. Finally, the supernatant was carefully separated from the pellet, and both were heated in an oven at 105 °C overnight. To determine the WSI% and the WAC, equations (3) and (4) were used.

$$WAC\left(\frac{w}{w}\right) = \frac{Sediment\ weight}{Dry\ weight\ sample} \tag{3}$$

$$WSI\ (\%) = \frac{Dry\ solid\ supernatant\ weight}{Dry\ weight\ sample} * 100 \tag{4}$$

2.5. Physical analysis

The pancake's diameter and thickness were measured with a caliper. The moisture content was determined by the AACC method 44-15 A, and the water activity (a_w) was determined using a Hygropalm HC2-AWmeter (Rotronic Italia, Milano, Italy) at 25 °C (Lomuscio et al.,

Table 1
Pancake formulations of the control sample (CP) and pancakes with increasing levels of *A. domesticus* (AP10, AP20, and AP30) (quantities are expressed in g).

Sample	Wheat flour	Water	Egg white	Sugar	Salt	Baking powder	*A.Domesticus* flour
CP	88	82	40	16	3	3	–
AP10	79.2	82	40	16	3	3	8.8
AP20	70	82	40	16	3	3	18
AP30	62	82	40	16	3	3	26

2022).

2.6. Texture analysis

The Texture profile analysis (TPA) was determined on cooked pancakes with a texture analyzer (TX-700, Lamy rheology, France) equipped with a 5-kg load cell. A cylindrical probe (2.5 cm in diameter) was set at a speed of 1 mm/s for the hardness, chewiness, and cohesiveness measurements. A speed for return of 1 mm/s instead of the distance and the return position were selected depending on the pancake's height to keep the same 50% compression for all the samples.

2.7. Image analysis

After the cooking and cooling, the pancake samples were sliced transversely to obtain a circular sheet of 1–2 mm in height and about 20 cm^2 in area. Firstly, it was necessary to take an image scan of the pancake's sections via a commercial camera (Canon eos 2000D EF-S 18–55 IS II, Taiwan). Scanned color images were converted to grayscale and binarized with ImageJ (version 1.8.0) to obtain the pore area fraction, pore density, perimeter, and circularity.

2.8. Color determination in pancake samples

The analysis was carried out with a reflectance colorimeter (Illuminant D65) (Minolta Chroma meter CR-300, Osaka, Japan) according to the CIE-L^* a^* b^* system. In the CIE-L^* a^* b^* system L* value represents the lightness ranging from 0 (black) to 100 (white), and a^* and b^* are chromaticity coordinates. In particular, a* represents red and green values, while b* represents yellow and blue components (Ly, Dyer, Feig, Chien, & Del Bino, 2020). The pancakes were placed on a clear worktable, and then the measurements were performed at five different points on the smooth pancake's surface. Color change in pancake samples compared to the CP was assed applying the Equations (5) and (6):

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (5)$$

$$\Delta L = \left(L - L^0\right); \Delta a = \left(a - a^0\right); \Delta b = \left(b - b^0\right) \quad (6)$$

Where: ΔE = Total color difference

ΔL* = L* control−L* treatment; Δa* = a* control−a* treatment; Δb* = b* control−b* treatment

2.9. Statistical analysis

All data were processed with the analysis of variance (ANOVA) with a post-hoc Tukey's test ($p < 0.05$). Pearson's correlation tests and statistical analyses were performed using the software XLSTAT Premium Version (2021.1.1, Addinsoft SARL, Paris, France). Results were reported as mean values and standard deviation of at least three measurements.

3. Results and discussion

3.1. Water absorption capacity (WAC) and water solubility index (WSI)

WAC indicates the flour's functionality to bind and hold water, while WSI indicates the solubilization of small molecules in water (Oikonomou & Krokida, 2011; Rainero et al., 2022).

Table 2 showed that AP had a significantly higher WAC than other samples, while WAC presented similar values for WF and the different WF/AP mixed samples (AP10, AP20, and AP30). WF, AP10, AP20, and AP30 showed lower WAC values by about half than AP, contrary to the data reported by Alvarez-Barajas et al. (2023), using corn flour previously treated with a thermal process (nixtamalization) to produce AP-fortified tortillas. These authors assumed that the higher value of WAC was due to the presence of damaged starch in thermally pretreated corn flour, which led to a higher water-holding capacity (Barrera, Pérez, Ribotta, & León, 2007; Wang et al., 2020). In the present study, the WAC of WF and mixed samples suggest that WAC could depend on starch content by WF. Bresciani et al. (2022), and Rumpold and Schlüter (2013a) stated that AP did not contain starch granules, so its contribution to water absorption is limited. Similarly, Pilco-Romero et al. (2023) suggested that lower values in water absorption could also depend on the AP amino acid content. The WSI shows values significantly higher in AP than in WF and WF/AP mixed samples (AP10, AP20, and AP30). AP contains low molecular weight molecules, such as soluble fiber, dextrin, and water-soluble proteins and minerals that increase the solubility of the AP, as reported by Oikonomou et al. (2011). Other authors concluded that AP in extruded corn snacks increased the WSI parameter of the fortified sample and decreased water absorption (Ruszkowska et al., 2022; Stone, Tanaka, & Nickerson, 2019).

Table 2
Water Absorption Capacity and Water Solubility Index for the control sample (CP) and pancakes with increasing levels of *A. domesticus* (AP10, AP20, and AP30).

Sample	WAC (w/w)	WSI (%)
WF	1.60 ± 0.01^{b}	4.50 ± 0.01^{bc}
AP	2.67 ± 0.05^{a}	7.59 ± 0.14^{a}
AP10	1.65 ± 0.03^{b}	4.75 ± 0.01^{c}
AP20	1.67 ± 0.01^{b}	5.04 ± 0.06^{b}
AP30	1.68 ± 0.02^{b}	5.14 ± 0.1^{b}

Data are expressed as mean ± standard deviation. Values with different superscripts within the same column significantly differ for $p < 0.05$.

3.2. Rheological analysis

Table 3 reported the rheological findings of the different pancake sample batters. The flow index (n) allows to establish the rheological behavior of a fluid: if it is equal to 1, it corresponds to a Newtonian fluid, and $n < 1$ and $n > 1$ correspond to a shear-thinning or shear-thickening flow behavior, respectively (Fischer, Pollard, Erni, Marti, & Padar, 2009). According to the statistical analysis, adding AP did not influence the flow index. Overall, "n" ranged from 0,54 (AP10) to 0,58 (AP30), suggesting that all the batters showed a shear-thinning behavior (pseudoplastic) (Bianchi, Cervini, Giuberti, & Simonato, 2023). The consistency index (K) describes the viscous nature of a system (Koocheki, Mortazavi, Shahidi, Razavi, & Taherian, 2009). AP30 showed a higher K value, significantly different from all the other samples, while AP10 and AP20 showed an increased, not significantly different, K index compared to CP. An increasing trend between K and the rate of substitution with AP is also in accord with Khatun, Van Der Borght, Akhtaruzzaman, and Claes (2021). They attributed the increase in consistency to the strong crosslinked structure in doughs formed by the protein content of cricket powder. According to Kırbaş, Kumcuoglu, & Tavman (2019) and Yi and Li, 2022, consistency could depend on protein and

Table 3
Rheological parameters for different batters of the control sample (CP) and pancakes with increasing levels of *A. domesticus* (AP10, AP20, and AP30), calculated with the power law model: consistency index (*K*) and flow index (*n*).

Sample	Flow index (n)	Consistency index (k) mPa s	r^2
CP	$0,56 \pm 0,01^{a}$	4346 ± 51^{b}	0,99
AP10	$0,54 \pm 0,06^{a}$	4599 ± 34^{b}	0,99
AP20	$0,57 \pm 0,03^{a}$	5161 ± 62^{b}	0,99
AP30	$0,58 \pm 0,01^{a}$	9905 ± 13^{a}	0,99

These values are the mean ± SD of three independent experiments. The means were compared using ANOVA with a post-hoc Tukey's test at $p < 0.05$. Data with different lowercase letters in each line are significantly different.

dietary fiber content that would interfere with the free water available. Briefly, the consistency of fortified samples was strongly affected by the AP functional properties. Except for CP, from AP10 to AF 30, there is an increasing and significant positive correlation between k and density (Appendix A Supplementary data). For AP30, the consistency index was 53.6% higher than CP. Bozdogan, Ormanli, Kumcuoglu, and Tavman (2022) reported that batters characterized by high viscosity could struggle to incorporate more air during the mixing process, thus resulting in higher-density and lower-volume products. Thus, an optimal air quantity incorporation would require increased mixing energy.

3.3. Texture analysis

Pancake samples with different levels of AP substitution significantly differed from CP for hardness, chewiness, and cohesiveness parameters, as reported in Table 4. The samples' hardness significantly increased from 5.63 (CP) to 12.13 N (AP30), while chewiness ranged from 6.49 to 10.46 N, respectively. According to Perez-Fajardo et al. (2023), adding insect powder led to products that required more chewing force. Mafu, Ketnawa, Phongthai, Schönlechner, and Rawdkuen (2022), Bawa, Songsermpong, Kaewtapee, and Chanput (2020), Roncolini et al. (2019), and Burt et al. (2020) observed the same textural behavior in bread fortified with cricket powder, reporting an increase in hardness and chewiness parameters. Moreover, Roncolini et al. (2019) affirmed that CP caused an increase in hardness and chewiness parameters in baked products, probably due to the dilution and, subsequentially, the weakening of the gluten matrix caused by the replacement of the WF. The increasing level of CP alters the gluten structure, which is essential to determining the dough's structure and elastic properties. Others, like Cavalheiro et al. (2023), working with CF-fortified frankfurters, associated the increase in hardness and chewiness with the higher protein content of CF.

Similarly, Duda, Adamczak, Chełmińska, Juszkiewicz, and Kowalczewski (2019) and Pasini et al. (2022) observed a significantly higher hardness value in pasta enriched with cricket powder than that observed for control pasta. The protein content could have promoted a denser protein matrix that was more compression-resistant due to some additional interprotein bonds (Zhou et al., 2014). Cohesiveness slightly decreased with the increasing level of AP addition, with a significant difference for AP20 and AP30. Cohesiveness was higher in the control sample and AP10, with a significant decrease in samples AP20 and AP30. Prieto-Vázquez Del Mercado et al., 2022 obtained similar results in bread fortified with cricket powder. Çabuk. (2021) also attributed the decrease in cohesiveness in cricket powder-fortified bakeries to gluten weakening. In this study, chewiness and hardness were positively correlated with the AP rate of fortification, while cohesiveness showed no correlation. Borges, Da Costa, Trombete, and Câmara (2022) observed that cohesiveness reduction depended on the degree of AP fortification when substituted up to 20% with wheat flour.

Table 4
Textural characteristics of the control sample (CP) and pancakes with increasing levels of *A. domesticus* (AP10, AP20, and AP30).

Sample	Hardness (N)	Cohesiveness	Chewiness (N)
CP	5.76 ± 0.56^{d}	0.82 ± 0.03^{a}	5.07 ± 0.24^{c}
AP10	8.22 ± 0.67^{c}	0.83 ± 0.02^{ab}	6.49 ± 0.26^{b}
AP20	10.07 ± 0.89^{b}	0.79 ± 0.03^{b}	7.40 ± 0.34^{b}
AP30	11.83 ± 1.14^{a}	0.80 ± 0.07^{b}	10.46 ± 0.89^{a}

Data are expressed as mean ± standard deviation. Values with different superscripts within the same column significantly differ for $p < 0.05$.

Table 5
Pore characterization of the control sample (CP) and pancakes with increasing levels of *A. domesticus* (AP10, AP20, and AP30).

Sample	Area fraction (%)	Pore area (mm^2)	Pore density ($pore/cm^2$)	Perimeter (mm)	Circularity (%)
CP	8.60 ± 0.81^{a}	0.41 ± 0.03^{a}	12.88 ± 6.16^{b}	2.11 ± 0.01^{a}	0.84 ± 0.12^{a}
AP10	7.20 ± 0.46^{a}	0.35 ± 0.02^{ab}	41.94 ± 6.87^{a}	2.03 ± 0.04^{a}	0.69 ± 0.19^{b}
AP20	6.63 ± 0.74^{a}	0.27 ± 0.05^{ab}	41.36 ± 5.43^{a}	2.07 ± 0.03^{a}	0.64 ± 0.08^{b}
AP30	5.20 ± 0.64^{a}	0.26 ± 0.03^{b}	38.30 ± 2.76^{a}	1.87 ± 0.03^{a}	0.64 ± 0.12^{b}

Data are expressed as mean ± standard deviation. Values with different superscripts within the same column significantly differ for $p < 0.05$.

3.4. Image analysis

The data reported in Table 5 showed that only pore density and circularity parameters presented significative differences between the control and the other fortified samples. Cross-sections and top sections of pancake samples are reported in Fig. 1. Replacing WF with AP reduced the circularity of pores, contrary to what was reported by Rodríguez-García, Puig, Salvador, & Hernando, 2012. The pore density, expressed as the pore number per cm^2, increased in AP samples, mainly in AP10 and AP20, compared to CP. Similarly, Bartkiene et al. (2023), Noyens et al. (2021), and Da Rosa Machado and Thys, 2019 reported that increasing amounts of AP increased the porosity of bread. Some authors suggested that this could depend on the AP protein's physicochemical properties, such as structure, solubility, and hydration in formulations, while others attributed this effect to chitosan, whose structure led to more porous crumbs (Ghoshal & Mehta, 2019; Kerch, Zicans, & Meri, 2010; Melgar-Lalanne, Hernández-Álvarez, & Salinas-Castro, 2019; Çabuk, 2021). The ratio of the total area covered by the pores was also evaluated compared to the total area of pores that defined the area fraction (Baset, Villafranca, Guay, & Bhardwaj, 2013). The pore's perimeter and area fraction results were not significantly different. Indeed, the data obtained for the perimeter were similar from CP to AP30. The area fraction showed a similar trend even if AP30 had a lower value. The correlation test supported this; indeed, the area fraction was negatively correlated with the AP rate, suggesting that this could depend on the AP composition regarding protein and fiber, hardness, and cohesiveness (Appendix A Supplementary data).

3.5. Physical characteristics, moisture, and water activity

Table 6 reported the results for the experimental samples' moisture content, diameter, height, and water activity. The a_w parameter indicates the degree of microbial stability of food (Rahman & Labuza, 2020) and showed no significant difference among samples. AP30 revealed a significantly reduced moisture content value (46.75 ± 0.23)

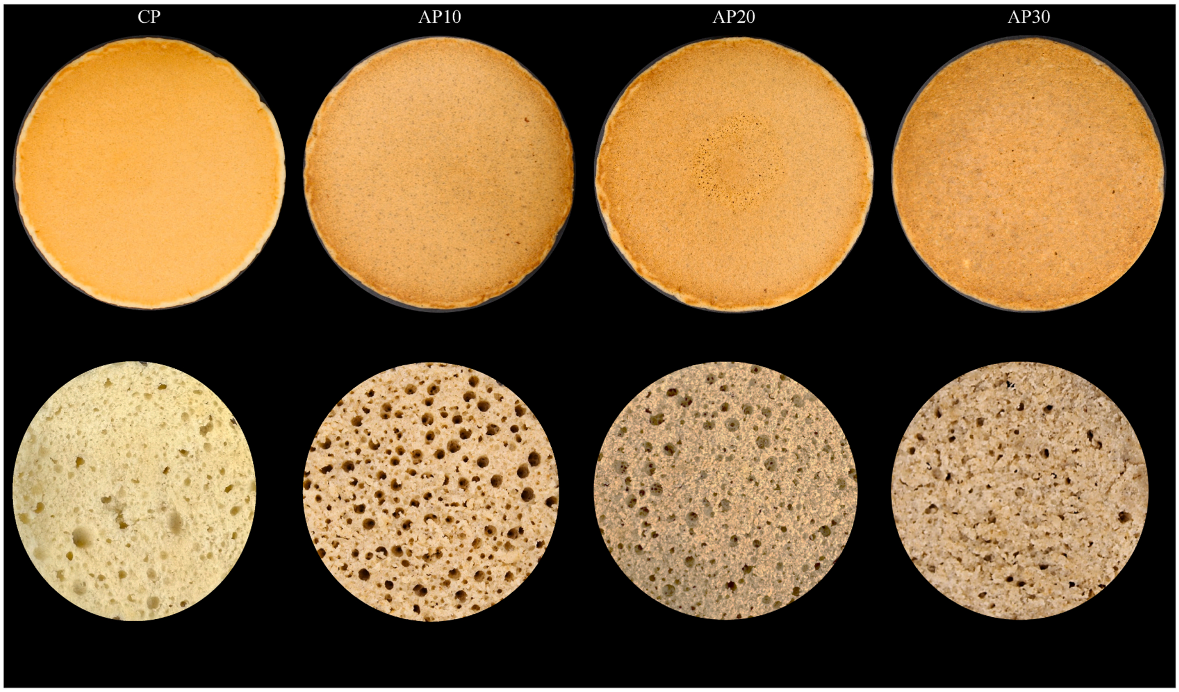


Fig. 1. Cross-sections and top sections of control sample (CP) and pancakes with increasing levels of *A. domesticus* (AP10, AP20, and AP30).

Table 6
Physical characteristics, moisture, and a_w of the control sample (CP) and pancakes with increasing levels of *A. domesticus* (AP10, AP20, and AP30).

Sample	Diameter (cm)	Height (cm)	Moisture (%)	a_w
CP	8.13 ± 0.06^b	1.08 ± 0.05^a	48.23 ± 0.48^a	0.91 ± 0.01^a
AP10	9.04 ± 0.01^a	1.13 ± 0.04^a	47.53 ± 0.12^a	0.90 ± 0.01^a
AP20	8.95 ± 0.06^a	1.13 ± 0.02^a	47.52 ± 0.24^a	0.91 ± 0.01^a
AP30	8.41 ± 0.25^b	1.19 ± 0.06^a	46.75 ± 0.23^b	0.91 ± 0.02^a

Data are expressed as mean ± standard deviation. Values with different superscripts within the same column significantly differ for $p < 0.05$.

compared to the control and the other fortified samples, while Chetana, Sudha, Begum, and Ramasarma (2010) and Bender et al. (2017) observed opposite results. They hypothesized that adding fiber to food formulations could increase the moisture content, but in AP30, this was not true, even if the fiber content increased (Kowalski et al., 2022). In the present paper, substituting WF with AP could have affected the batter's capacity to retain water during cooking. The negative correlation between moisture and protein content supported this assertion (Appendix A Supplementary data). CP showed the lowest diameter and height values. AP fortified samples are characterized by a 7% diameter decrease and a 9.2% height increase from AP10 to AP30. It is interesting to note that from AP10 to AP30, there is an increase in the height, together with a decrease in diameter, contrary to the data reported by Perez-Frajando et al. (2023), who observed that the addition of AP to bread caused a reduction in the height of products due to the higher

Table 7
Color parameters (CIELAB) of the CP and pancakes with increasing levels of *A. domesticus* (AP10, AP20, and AP30) and ΔE between samples are reported.

Sample	L*	a*	b*	Sample confrontation	ΔE
CP	71.30 ± 0.73^a	7.37 ± 0.56^b	34.30 ± 0.44^a	CP-AP10	9.61
AP10	62.54 ± 0.20^b	9.32 ± 0.21^b	30.87 ± 0.07^b	CP-AP20	12.43
AP20	60.09 ± 0.65^b	8.71 ± 0.37^b	29.11 ± 0.09^c	CP-AP30	19.47
AP30	53.10 ± 2.55^c	11.58 ± 1.11^a	28.82 ± 0.46^c	AP10-AP20	3.08
				AP20-AP30	7.56
				AP10-AP30	9.92

Data are expressed as mean ± standard deviation. Values with different superscripts within the same column significantly differ for $p < 0.05$.

Table 8
Pancake's proximate composition (g/100 g) from the control sample (CP) to the most fortified sample (AP30). Carbohydrates, protein, fat, dietary fiber, and ash content are calculated based on fresh weight.

Sample	Carbohydrates	Protein	Fat	Dietary fiber	Ash
WF	69.10 ± 9.54	11.23 ± 0.28	0.20 ± 0.04	2.11 ± 0.32	15.74 ± 0.31
AP	4.53 ± 0.37	50.89 ± 0.24	23.66 ± 2.05	8.64 ± 0.39	2.66 ± 0.30
CP	34.69 ± 1.56^a	5.8 ± 0.1^c	0.45 ± 0.04^d	0.91 ± 0.02^d	5.62 ± 0.06^a
AF10	33.22 ± 0.46^a	6.43 ± 0.2^c	1.05 ± 0.01^c	1.05 ± 0.01^c	5.52 ± 0.07^a
AF20	30.87 ± 0.21^b	7.55 ± 0.01^b	1.81 ± 0.09^b	1.27 ± 0.03^b	5.22 ± 0.07^b
AF30	29.07 ± 0.54^c	8.63 ± 0.11^a	2.37 ± 0.04^a	1.40 ± 0.04^a	4.85 ± 0.15^c

These values are the mean ± SD of three independent experiments. The means were compared using ANOVA with a post-hoc Tukey's test at $p < 0,05$. Data with different lowercase letters in each line are significantly different.

amount of insoluble proteins that could have interfered with the gluten matrix, reducing the degree of dough extensibility. Our result could be attributed to the decreasing pore area and the increasing pore density (Table 6) among the fortified pancakes, even if this was not stated in the correlation matrix but was in accord with Yazici and Ozer (2021), who reported that it is desirable to gain tiny and numerous bubbles in the bakery to obtain a product with a higher volume.

3.6. Color determination in pancake samples

The color parameter could influence consumers' perception of food. Table 7 reported that AP fortification decreased brightness (L* value) from CP to AP30 samples, as confirmed by the correlation matrix (Appendix A Supplementary data) where L* negatively correlates with AP rate. ΔE values correspond to the color difference between two samples (Barath, Faber, Westland, & Niedermeier, 2003). In this study, ΔE was higher compared with AP-fortified samples. From CP to AP30, increased *a** value and decreased *b** value. This trend was like what observed in pancakes by Mazurek et al. (2022). All these observations might depend on the darker color of AP and the enzymatic browning reactions given by the protein content, even if not supported by the correlation reported in Appendix A Supplementary data (Zhao, Vázquez-Gutiérrez, Johansson, Landberg, & Langton, 2016).

3.7. Proximate composition of A. domesticus flour, and pancakes

Table 8 reported the chemical compositions of wheat flour (WF), *Acheta domesticus* powder (AP), and experimental pancakes. Nevertheless, the chemical composition of insects can significantly vary according to species, development stage, and feeding (Kouřimská & Adámková, 2016). Table 8 shows a decrease in carbohydrates of 16.2% from CP to AP30, while the fat content increased by 81% in AP30. It is to be underlined that the AP, rich in polyunsaturated fatty acids, can undergo an oxidation process. The protein content is 41.2% higher in AP30 than in CP. Nevertheless, protein digestibility and bioavailability should be further investigated to evaluate the nutritional value. Minerals decreased by 13.7% in AP30, but other investigations on mineral bioavailability are needed (Van Huis et al., 2021).

AP30 exhibits an increase of fiber of about 52.9% compared to CP. Insect fibers primarily comprise chitin and chitosan that positively impact human health. Chitin is an insoluble fiber that can be soluble at specific acid conditions; in general, the soluble dietary fiber can lower the adsorption of sugar and cholesterol, while the insoluble ones help in bulking and, therefore, facilitate better bowel movement. Chitin from edible insects may be a functional prebiotic due to its ability to stimulate the growth of certain beneficial bacteria, which may help solve gut health problems by acting directly as an antimicrobial or as a prebiotic to feed probiotic bacteria (Kipkoech, 2023).

4. Conclusions

Consumer interest and recent European regulations have promoted edible insects' utilization in food formulation. The present study aimed to determine the technological and compositional features of pancakes fortified with 10, 20, and 30% *Acheta domesticus* powder. The insect powder supply chain could represent an opportunity to reduce the environmental impact compared to common livestock farming since insects require less water and less soil for rearing. Interestingly, the insect powder has changed the composition of fortified pancakes, increasing fiber, protein, and fat, mainly polyunsaturated, which is potentially healthier compared to animal fats. The observation of the technological and physical characteristics showed that although there were minor differences in specific parameters, the samples' fortification did not drastically alter technological parameters. Instead, some issues could come from high-fat content that could affect oxidation stability. To overcome these problems and make products marketable and consumable, they should either be destined for ready consumption or be subjected to preservation treatments in a protective atmosphere or using food preservatives. To conclude, it emerges that AP could represent a valuable ingredient to fortified baked goods with particular attention to respect and achieve some goals supported by the UE Green Deal.

5. Future recommendations

However, for a complete understanding of the nutritional value of pancakes or other food products containing insect flour, several factors must be considered, which will require further studies. Determining proteins by nitrogen quantification with the Kjeldal method leads to an overestimation due to the glucosamine and *N*-acetylglucosamine hydrolysis of chitin. Furthermore, the presence of proteins bound to the exoskeleton that are unavailable (inaccessible proteins) for digestion and absorption by the gastrointestinal tract has been described. Even the oxidation of lipids during the drying and storage processes of insect powder can modify the nutritional profile of the raw material and contribute to triggering protein oxidation phenomena, which could become even less bioavailable. Finally, each food has its specific thermal history, which, once again, could modify the nutritional profile of the finished product. For all these reasons, in the future, *in vitro* digestion studies and experimental tests on animal models will be necessary to describe the nutritional profile of these innovative products.

Funding

This research received no external funding.

CRediT authorship contribution statement

Margherita Bruttomesso: Writing – original draft, Visualization, Formal analysis, Data curation. **Federico Bianchi:** Writing – review & editing, Supervision. **Ilaria Pasqualoni:** Formal analysis. **Corrado Rizzi:** Writing – review & editing. **Barbara Simonato:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

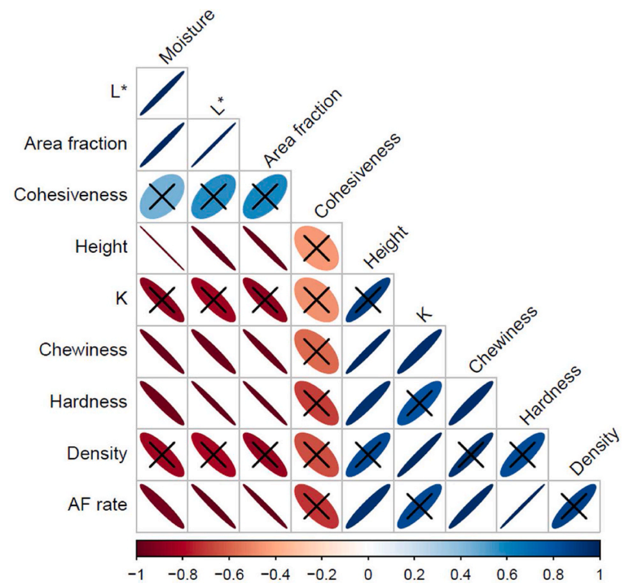
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.lwt.2024.116073.



APPENDIX A1. Correlation analyses graphical representation.
K: consistency index; AF rate: *A. domesticus* fortification rate; L*; lightness (CIELAB system).
Positive correlations are displayed in blue, and negative correlations in red, as indicated by the bar at the bottom of the graph. Color intensity and the expansion of the ellipses are proportional to the correlation coefficients.
The reported values represent Pearson's coefficients, whereas dark blue ellipses represent significative differences for p-value<0.05. the right is depicted as a scale used as a reference for the color in the main table.

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