Comparing the quality of two traditional fried street foods from the raw material to the end product: The Beninese cowpea-based ata and the Italian wheat-based popizza

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Abstract
Street food plays a recognized socioeconomic role, offering opportunities of employment particularly for women and providing cheap food to lower income people. West Africa is characterized by a great diversity of traditional foods, widely consumed but poorly investigated. Ata is a fried dough made of cowpea flour, very popular in Benin. In Southern Italy, popizza is prepared in a very similar way as ata, but using wheat flour. This work aimed at comparing the main physicochemical characteristics of ata and popizza, from the raw material to the end product. Cowpea flour showed significantly higher levels of proteins (23.25 vs. 13.48 g 100 g⁻¹ on dry matter), total phenolic compounds (0.73 vs. 0.41 mg g⁻¹ of ferulic acid d.m.), antioxidant activity (2.84 vs. 0.86 μmol Trolox g⁻¹ d.m.), as well as higher water absorption capacity (1.01 vs. 0.61 g water per gram flour) and particularly higher water solubility index (23.01 vs. 6.69 g 100 g⁻¹) than wheat flour. The two flours showed different pasting characteristics: starch swelling occurred at a lower temperature in cowpea than in wheat flour and produced a less viscous gel. Due to absence of gluten and limited viscosity of starchy fraction, ata was less porous and more springy than popizza. Moreover, ata showed higher oil uptake than popizza (22.2 vs. 14.1 g oil 100 g⁻¹ product) and was also characterized by a browner surface than popizza. Knowledge about the quality features of these traditional foods and their raw material could enhance their marketing, with positive effects on local economy.

KEYWORDS
ata, cowpea flour, phenolic compounds, popizza, street food, traditional food, wheat flour

1 | INTRODUCTION

The preparation of street food plays a recognized socioeconomic role, offering opportunities of employment particularly for women and providing food at affordable cost to lower income people (Okojie & Isah, 2014). On the other hand, the way street foods are prepared arises several food safety issues. Among street foods, those prepared by frying and immediately consumed are the safest (Rane, 2011).

Cowpea (Vigna unguiculata L. Walp), also known as black-eyed pea, is the fifth most produced pulse in the world (Food and Agriculture Organization, 2017) and has the peculiar characteristic of growing in semiarid and dry environments. Owing to its drought tolerance, cowpea production is mainly concentrated in Africa (Gómez, 2003).
West Africa, in particular, where cowpea is commonly and traditionally consumed, accounts for the majority of the world production (Food and Agriculture Organization, 2017). Characterized by a high content of proteins (Jayathilake et al., 2018), cowpea is the principal proteinaceous food for a nutritionally vulnerable population.

African food culture is characterized by several indigenous and traditional food products, widely consumed but poorly investigated (Madodé et al., 2011). In Benin, cowpea is the basic ingredient in the preparation of abobo (boiled cotyledons), ata (fried dumplings, also named atta), magni-magni (steam cooked paste), adowè (purée), and atacle (very dry fritters; Dovlo, Williams, & Zoaka, 1976; Madodé et al., 2011). In particular, ata is a fried street food eaten at breakfast, lunch, or as a snack, popular also in Togo, Nigeria (where is named akara) and Ghana (where is named koose) (Madodé et al., 2011). Ata is traditionally made by steeping, wet dehulling, and then grinding cowpea beans. The resulting paste is then used to prepare a batter that can be variously seasoned prior to deep frying (Madodé et al., 2011). To skip the laborious and time-consuming traditional wet dehulling, the batter can be prepared more rapidly starting from dry-milled cowpea flour (Dovlo et al., 1976; Ihediohanma, Ofoedu, Ojimba, Okafor, & Adedokun, 2014; Kethireddipalli, Hung, McWatters, & Phillips, 2002). The nutritional composition of ata has already been investigated, showing high fat content but also a good protein content and an interesting presence of micronutrients such as calcium, iron, and zinc (Madodé et al., 2011). Cowpea processing into ata is traditionally made by women, and the income consequent to the sale of these fritters contributes to poverty reduction (Agazounon, Coulibaly, & Houndekon, 2004).

Very far from Benin, in the Apulia region of Southern Italy, a fried street food named popizza (plural popizze, also named pettole, pl. pettole) is traditionally prepared in a very similar way as ata (Trabace, 2015). Popizza is prepared from common wheat flour, instead of cowpea flour in the case of ata, and its artisanal production has become an unexpected source of income for Apulian jobless women, who prepare this dish at the corners of the streets close to historical sites. Such practice recalls the picture of ata production in Benin and also in West Africa. Popizza is much appreciated by locals, as well as by the increasing number of tourists visiting Apulia, being tasty and inexpensive. However, despite its popularity, popizza has never been studied, and there are no scientific data about its characteristics.

In this frame, the aim of this work was to define the main quality characteristics of these two poorly studied traditional street foods, ata and popizza, starting from the analysis of the flours used for their preparation.

2 | MATERIAL AND METHODS

2.1 | Raw material

Refined flour of cowpea (Vigna unguiculata L. Walp.), produced in Benin by a local company (Produits Dajo, Abomey-Calavi, Benin), was kindly provided by Laboratory of Food Sciences of the University of Abomey-Calavi, Abomey-Calavi, Benin. Refined flour of common wheat (Triticum aestivum L.) “0” type (Selezione Casillo, Corato, Italy) was purchased in Italy at local retailers. The quality characteristics of 0 type flour are legally ruled (Italian Presidential Decree, 2001). Compressed baker’s yeast (Saccharomyces cerevisiae, “Pinnacle” yeast, AB Mauri, Casteggio, Italy) and salt (Piazzolla Sali, Margherita di Savoia, Italy) were purchased at local Italian retailers.

2.2 | Preparation of ata and popizza

Ata and popizza fritters were prepared at the Food Science laboratories of the Department of Soil, Plant and Food Science of the University of Bari, Italy. Ingredients of ata were the following: 100 g of cowpea refined flour, 120 ml of tap water, 2.5 g of compressed baker’s yeast, and 4 g of salt. Ingredients of popizza were the following: 100 g of wheat refined flour “0” type, 95 ml of tap water, 2.5 g of compressed baker’s yeast, and 4 g of salt. The amount of water was adjusted so that a batter with similar consistency was obtained both for ata and popizza. Ata and popizza fritters were prepared according to the procedure mentioned on cowpea flour packaging. Flour and yeast were put in a bowl and water at room temperature was added little by little, while constantly mixing (manually, with a fork) for 5 min, in order to obtain a homogeneous mixture without lumps. Then, salt was added and the mixture was stirred for other 15 min. The dense batter thus obtained was left to rise in the bowl, covered by a clean cotton cloth, for 90 min at room temperature (approximately 25°C). After leavening, batter portions of uniform size (sphere, 4.0 ± 0.3-cm diameter) were taken with the help of two tablespoons and immersed in extra virgin olive oil, previously heated to 150°C, for deep frying (Zephir deep fryer, ZHC501, Westim S.p.A., Rome, Italy). Ata was fried for 6 min, whereas popizza for 10 min. The frying time was defined in preliminary trials to obtain perfect cooking at the center of the products, assessed by cutting and inspecting them. Samples were left to cool spontaneously at room temperature and immediately analyzed.

2.3 | Flour particle size distribution

The particle size distribution was analyzed by a LabSifter (KBFSN, Buhler, Switzerland). Flours (100 g) were sifted for 5 min on sieves with opening of 425, 300, 212, 150, and 106 μm. The analysis was carried out in triplicate.

2.4 | Flour chemical composition

Protein (total nitrogen × 5.7), ash, and moisture contents were determined according to the Association of Official Analytical Chemists (AOAC) methods 979.09, 923.03, and 925.10, respectively (AOAC, 2006). Total dietary fiber was determined by the enzymatic-gravimetric procedure described in the AOAC method 991.43 (AOAC, 2006). Lipid content was determined by means of a Soxhlet apparatus using diethyl
ether (Sigma Aldrich, Milan, Italy) as extracting solvent (AOAC, 2006). Total carbohydrate content was obtained by subtracting from 100 g of flour, on dry basis, its content of protein, lipid, ash, and dietary fiber. The fatty acid composition was determined by gas chromatographic analysis of fatty acid methyl esters according to AOCS method Ch 1–91 (AOCS, 1993), with the conditions previously described in Summo et al. (2019a). All determinations were performed in triplicate.

### 2.5 | Total phenolic compounds and antioxidant activity of flours

An aqueous-methanol extract (20/80 v/v) was prepared as follows: 1 g of flour was mixed with 10 ml of solvent in a centrifuge tube, stirred for 2 hr in the dark, and centrifuged at 12,000 × g for 3 min to recover the supernatant. The total phenolic compounds were then determined using the method of Pasqualone et al. (2015) and expressed in milligram per gram of flour on dry matter, with ferulic acid being one of the most represented phenolic compounds in both cowpea (Gutiérrez-Uribé, Romo-Lopez, & Serna-Saldívar, 2011) and wheat (Hernández, Afonso, Rodríguez, & Díaz, 2011). The antioxidant activity was evaluated by the 2,2-diphenyl-1-picrylhydrazyl radical scavenging capacity assay as reported in Pasqualone et al. (2015) and was expressed as μmol Trolox equivalent g⁻¹ on dry matter. The determinations were performed in triplicate.

### 2.6 | Physicochemical properties of flours

Water absorption index (WAI), water solubility index (WSI), water absorption capacity (WAC), and bulk density of flours were determined according to the procedures reported by Du, Jiang, Yu, and Jane (2014). WAI (expressed in g swollen sediment g⁻¹ flour) and WSI (expressed in g dissolved solids 100 g⁻¹ flour) were assessed after heating a flour suspension in distilled water at 70°C, whereas WAC (expressed in g water g⁻¹ flour) was assessed at room temperature. All determinations were performed in triplicate.

### 2.7 | Pasting characteristics of flours

Starch properties were determined using a Brabender microviscoamylograph (Brabender Instruments, Duisburg, Germany), suspending 15 g of flour (14.0% moisture basis) in 100 ml of distilled water. The instrument was programmed to continuously stir at 250 rpm while performing heating and cooling steps as follows: from 30°C up to 95°C at the rate of 1.5°C/min, keeping 95°C for 30 min, cooling down to 50°C at 1.5°C/min, and holding 50°C for 30 min. The viscosity values at the peak (peak viscosity), at the end of the holding period at 95°C (minimum viscosity), and at the end of cooling period (cooling maximum viscosity) were recorded. The differences between peak viscosity and minimum viscosity and between cooling maximum viscosity and minimum viscosity were evaluated as breakdown (BD) and setback, respectively. All determinations were performed in triplicate.

### 2.8 | Color of ata and popizza fritters

Instrumental determination of surface and inner color of ata and popizza fritters was carried out using the CM-600d colorimeter (Konica Minolta, Tokyo, Japan) supported by SpectraMagic NX software (Konica Minolta, Tokyo, Japan). Lightness (L'), redness (a'), and yellowness (b') were determined. All color determinations were replicated four times.

### 2.9 | Specific volume of ata and popizza fritters

Specific volume was determined by rapeseed displacement, as in AACC method 10-10 (AACC, 2000). The determination was performed in triplicate.

### 2.10 | Texture profile analysis of ata and popizza fritters

Texture profile analysis was carried out using the Z1.0 TN texture analyzer (Zwick Roell, Ulm, Germany) equipped with a 3.5-cm cylindrical probe and a 50-N load cell. The samples were subjected to a two-compression cycle, with 5 s of break and 1 mm s⁻¹ of speed, up to 40% of recorded deformation, with 10 replications.

### 2.11 | Image analysis of ata and popizza fritters

Ata and popizza fritters were cut in two halves, and the image of the inner was acquired using a Canon 600d DSLR camera (Canon, Tokyo, Japan), equipped with a Sigma 17–70 mm f/2.8 (Sigma Corporation, Kawasaki, Japan), saved in TIFF format with no compression, and processed by ImageJ software (National Institutes of Health, Bethesda, USA). Each image was converted into 8-bit grayscale, and a section of 25 × 25 mm was cropped from the center of the product, then it was filtered by thresholding function in order to obtain the best cell resolution. Image analysis was performed to detect the cells with an area >0.05 mm² and circularity in the range 0–1, where 1 is the value attributed to perfectly circular cells and 0 to thin thread-like cells. The total number of cells, mean area of all the observed cells, and cell density (number of cells/mm²) have been measured according to Scheuer et al. (2014). Three replicated analyses were done.

### 2.12 | Oil uptake of ata and popizza fritters

Oil uptake was determined by Soxhlet extraction as in Shih and Daigle (1999). Diethyl ether (Sigma Aldrich, Milan, Italy) was used as
extracting solvent. The extraction time accounted to 6 hr. Three replicated analyses were done.

2.13 | Statistical analysis

All the experimental data were subjected to one-way analysis of variance followed by the Tukey’s honestly significant difference test. Significant differences were determined at p < .05 by the XLStat software (Addinsoft SARL, New York, NY, USA).

3 | RESULTS

3.1 | Nutritional composition, bioactive compounds, and physicochemical properties of flours

As for nutritional composition, the protein content of cowpea flour reached 23.25 g 100 g\(^{-1}\) d.m., almost doubling the protein content of wheat flour (Table 1). On the contrary, the carbohydrate content was much lower in cowpea than in wheat flour.

The lipid fraction, significantly more abundant in cowpea than in wheat flour, was mostly constituted by polyunsaturated fatty acids (PUFAs), whose sum was higher in wheat than in cowpea flour (Table 2). Linoleic acid was the most represented fatty acid, followed by the linolenic one. The sum of monounsaturated fatty acids, mainly constituted by oleic acid, was higher in wheat than in cowpea flour. In cowpea flour, the content of saturated fatty acids (SFAs) accounted for 40.96% of total fatty acids, approximately doubling the value found in wheat flour. Palmitic acid was the most important SFA of cowpea flour, followed by stearic acid.

No significant differences between flours were found in the content of total dietary fiber that was slightly higher than 3 g 100 g\(^{-1}\) d.m. in both the flours, whereas ash content was higher in cowpea than in wheat flour (Table 1).

Cowpea flour was characterized by significantly higher levels of total phenolic compounds (0.73 mg g\(^{-1}\) of ferulic acid d.m.) than wheat flour (0.41 mg g\(^{-1}\) of ferulic acid d.m.). Owing to its higher content of total phenolic compounds, cowpea flour showed higher in vitro antioxidant activity than wheat flour (2.84 vs. 0.86 μM Trolox g\(^{-1}\) d.m.).

Cowpea and wheat flour showed a similar particle size distribution, but wheat flour was slightly coarser, with significantly higher amounts of particles in the ranges 212–300 and 150–212 μm.

Significant differences between cowpea and wheat flours were observed in terms of physicochemical properties. Indeed, the BD, which indicates the mass per unit of occupied volume, was significantly higher in cowpea than in wheat flour. Cowpea flour showed higher WSI (23.01 g dissolved solids 100 g\(^{-1}\) flour) and lower WA1 (2.96 g swollen sediment g\(^{-1}\) flour) than wheat flour (6.69 g dissolved solids 100 g\(^{-1}\) flour and 5.13 g swollen sediment g\(^{-1}\) flour, respectively). Moreover, cowpea flour showed higher WAC than wheat flour.

### TABLE 1 Average nutritional composition, bioactive compounds, and physicochemical properties of cowpea and wheat flours used to prepare ata and popizza fritters

| Component                                      | Cowpea flour | Wheat flour |
|------------------------------------------------|--------------|-------------|
| **Proximate composition and bioactive compounds** |              |             |
| Lipids (g 100 g\(^{-1}\) d.m.)                 | 1.95 ± 0.19  | 1.17b ± 0.05|
| Proteins (g 100 g\(^{-1}\) d.m.)               | 23.25 ± 0.35 | 13.48b ± 0.19|
| Carbohydrates (g 100 g\(^{-1}\) d.m.)           | 69.11b ± 0.46| 81.38b ± 0.26|
| Ashes (g 100 g\(^{-1}\) d.m.)                   | 2.55 ± 0.09  | 0.62b ± 0.02 |
| Total dietary fiber (g 100 g\(^{-1}\) d.m.)     | 3.14a ± 0.02 | 3.38b ± 0.02 |
| Total phenolic compounds (mg ferulic acid g\(^{-1}\)d.m.) | 0.73a ± 0.03 | 0.41b ± 0.02 |
| Antioxidant activity (μM Trolox g\(^{-1}\) d.m.) | 2.84a ± 0.05 | 0.86b ± 0.12 |
| **Particle size distribution**                  |              |             |
| >425 μm (g 100 g\(^{-1}\))                      | 0.3a ± 0.1   | 0.5a ± 0.2  |
| 300–425 μm (g 100 g\(^{-1}\))                   | 1.9b ± 0.1   | 2.7a ± 0.5  |
| 212–300 μm (g 100 g\(^{-1}\))                   | 7.9b ± 1.7   | 13.8a ± 1.3 |
| 150–212 μm (g 100 g\(^{-1}\))                   | 44.5b ± 4.2  | 57.5a ± 9.1 |
| 106–150 μm (g 100 g\(^{-1}\))                   | 28.2a ± 1.2  | 12.5b ± 2.1 |
| <106 μm (g 100 g\(^{-1}\))                      | 17.2a ± 4.5  | 6.9b ± 0.1  |
| **Physicochemical properties**                  |              |             |
| Bulk density (g ml\(^{-1}\))                    | 0.91a ± 0.00 | 0.84b ± 0.01|
| Water absorption index (g swollen sediment g\(^{-1}\) flour) | 2.96e ± 0.01 | 5.13e ± 0.02|
| Water solubility index (g dissolved solids 100 g\(^{-1}\) flour) | 23.01e ± 0.73 | 6.69e ± 0.60|
| Water absorption capacity (g water g\(^{-1}\) flour) | 1.01e ± 0.00 | 0.61e ± 0.00|
| **Pasting characteristics**                     |              |             |
| Pasting temperature at peak (°C)                | 77b ± 1      | 86a ± 1     |
| Peak viscosity (BU)                             | 457b ± 13    | 651a ± 19   |
| Minimum viscosity (BU)                         | 215b ± 11    | 354a ± 8    |
| Cooling maximum viscosity (BU)                 | 613b ± 9     | 1005a ± 21  |
| Breakdown (BU)                                 | 242a ± 6     | 297a ± 9    |
| Setback (BU)                                   | 398b ± 11    | 651a ± 17   |

ab Different superscript letters in the same row indicate significant differences at p < .05. Abbreviation: BU, Brabender Units.

The pasting properties of aqueous suspensions of cowpea and wheat flour were different. Cowpea paste showed a lower peak viscosity than wheat paste. When the gel was held at 95°C for 30 min, cowpea paste showed also a lower value of minimum viscosity than wheat paste. During subsequent cooling, cowpea formed a less firm gel than wheat flour (613 vs. 1,005 BU).
TABLE 2 Fatty acid composition (mean and standard deviation, expressed as g 100 g−1) and sum of saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA) fatty acids of cowpea and wheat flours used to prepare ata and popizza fritters

|                | Cowpea flour | Wheat flour |
|----------------|--------------|-------------|
| C16:0          | 1.85a ± 0.14 | 0.84b ± 0.06|
| C15:0          | 0.12b ± 0.01 | 0.15b ± 0.00|
| C16:1          | 25.15a ± 0.15| 18.90b ± 0.19|
| C16:2          | 0.11b ± 0.05 | 0.27a ± 0.02 |
| C17:0          | 0.35b ± 0.00 | 0.12a ± 0.00|
| C17:1          | 0.02b ± 0.01 | 0.09a ± 0.02 |
| C18:0          | 5.58b ± 0.02 | 1.26a ± 0.24 |
| C18:1          | 10.58b ± 0.61| 16.07b ± 0.06|
| C18:2          | 29.52a ± 0.06| 0.45a ± 0.16 |
| C20:0          | 1.89a ± 0.06 | 0.45a ± 0.16 |
| C20:1          | 18.54a ± 0.41| 3.85a ± 0.18 |
| C20:2          | 0.11 ± 0.00  | n.d.         |
| C22:0          | 0.08± ± 0.02 | 0.07± ± 0.00 |
| C23:0          | 3.74a ± 0.11 | 0.25± ± 0.07 |
| C24:0          | 0.42a ± 0.14 | 0.20± ± 0.21 |
| C24:1          | 1.86a ± 0.04 | 0.17± ± 0.01 |
| ΣSFA           | 40.96a       | 22.34b       |
| ΣMUFA          | 10.85b       | 16.42a       |
| ΣPUFA          | 48.19b       | 61.23a       |

Table 3 reports the colorimetric indices of ata and popizza, determined on both crust and crumb. The external surface of the two fritters showed a considerably different color. Ata was characterized by an intensely brown external color, whereas popizza showed a light yellow surface. Therefore, redness (a*) was higher in ata, whereas popizza had a significantly higher yellowness (b*) and lightness (L*).

The color of crumb was lighter than surface in both the fritters. Lightness of inner crumb did not show significant differences between ata and popizza, whereas both redness and yellowness were significantly higher in ata (2.27 and 21.43, respectively) than in popizza (0.26 and 17.25, respectively), although the differences in these parameters were low compared with those found for the crust.

TABLE 3 Surface and inner color, crumb texture and structure, and oil uptake of ata and popizza fritters

|                | Ata       | Popizza  |
|----------------|-----------|----------|
| Surface color  |           |          |
| L*             | 36.36± ± 2.43| 62.54± ± 5.43|
| a*             | 19.20± ± 1.71| 3.71b± ± 1.13|
| b*             | 23.48b± ± 4.07| 32.11b± ± 1.93|
| Inner color    |           |          |
| L*             | 69.52a ± 1.99| 68.61a ± 3.11|
| a*             | 2.27± ± 0.42 | −0.26± ± 0.14|
| b*             | 21.43± ± 1.08| 17.25b± ± 1.81|
| Crumb texture  |           |          |
| Springiness    | 0.84a± ± 0.05| 0.77b± ± 0.05|
| Gumminess (N)  | 12.45± ± 2.92| 9.83± ± 1.72|
| Chewiness (N)  | 10.45± ± 2.31| 8.31± ± 2.47|
| Cohesiveness   | 0.50± ± 0.09 | 0.54± ± 0.10|
| Hardness (N)   | 22.63± ± 3.01| 21.44± ± 4.00|
| Crumb structure|           |          |
| Mean cell area (mm²) | 0.43b± ± 0.09| 1.47± ± 0.55|
| Cell density (no. cells/mm²) | 524± ± 139| 73± ± 32|
| Number of cells | 220± ± 23    | 96± ± 19    |
| Specific volume (ml g⁻¹)  | 3.73± ± 0.51| 5.11± ± 0.19|
| Oil uptake (g oil 100 g⁻¹ product) | 22.2± ± 3.5 | 14.1± ± 0.5 |

Note. L*, a*, and b* indicate lightness, redness, and yellowness, respectively.

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3.2 | Physicochemical properties of fritters

3.2.1 | Surface and inner color

Table 3 reports the colorimetric indices of ata and popizza, determined on both crust and crumb. The external surface of the two fritters showed a considerably different color. Ata was characterized by an intensely brown external color, whereas popizza showed a light yellow surface. Therefore, redness (a*) was higher in ata, whereas popizza had a significantly higher yellowness (b*) and lightness (L*).

The color of crumb was lighter than surface in both the fritters. Lightness of inner crumb did not show significant differences between ata and popizza, whereas both redness and yellowness were significantly higher in ata (2.27 and 21.43, respectively) than in popizza (0.26 and 17.25, respectively), although the differences in these parameters were low compared with those found for the crust.

3.2.2 | Crumb structure and texture, oil uptake

Ata showed a more finely porous crumb structure than popizza, with a significantly higher number of cells (220 vs. 96 in ata and in popizza, respectively) (Table 3). The number of crumb cells identified is inversely related to cell area, therefore ata was characterized by a smaller cell area than popizza. Consequently, cell density, calculated as the number of observations divided by cell area, was also higher in ata than in popizza.

To better explain the results of image analysis, cell area was categorized in 12 classes. The relative frequency of each class is reported in Figure 1. In both fritters, the majority of cells were in the range 0.05–1 mm². The differences found considering separately the first three cell area classes (0.05–0.1, 0.1–0.2, and 0.2–1.0 mm²) were not significant. However, by considering the sum of cells in the range 0.05–1 mm², ata was characterized by the highest presence of small cells (p = .003). On the other hand, a significantly higher number of large cells was found in popizza crumb. In this case, the range of cells area was between 1 and 30 mm², with significant differences found only for the ranges 1–2, 2–4, 4–6, 6–8, and 10–15 mm² (Figure 1).

Regarding texture, although not significantly, ata was harder, gummier, and chewier than popizza. Significant differences, however, were observed for springiness that was higher in ata than in popizza fritters. Ata showed a lower specific volume than popizza.

Regarding oil uptake (Table 3), ata was characterized by a markedly higher oil uptake than popizza.
Different letters indicate significant differences at $p < .05$.

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**FIGURE 1** Cell area distribution of the inner surface of *popizza* and *ata* fritters. A total of 12 classes of cell areas were identified. Different letters indicate significant differences at $p < .05$.

4 | DISCUSSION

4.1 | Nutritional composition, bioactive compounds, and physicochemical properties of flours

As for wheat flour (Table 1), protein and ash content met the requirements of current Italian rules for “type 0” category (Italian Presidential Decree, 2001). Lipid content and fatty acid composition (Table 2) agreed with previous works (Antova, Stoilova, & Ivanova, 2014; Carvalho et al., 2012; Madodé et al., 2012). Also fiber content was within the range observed by other authors: Rivas-Vega et al. (2006) reported 2.6 g $100$ g$^{-1}$ of gallic acid, depending on the variety (Adjei-Fremah, Jackai, & Worku, 2015). The phenolic compounds are mainly located in the seed coat, thus the production process of cowpea flour causes a loss in phenolics (Adebooye & Singh, 2007).

The physical characteristics, which have a strong influence on food properties, showed significant differences between the two flour types. The cowpea flour showed higher BD than wheat flour, probably also due to the finer particle size compared with wheat flour. The values observed for cowpea flour were higher than those reported in previous studies for raw cowpea flours (Akubor, 2003; Appiah, Asibu, & Kumah, 2011). Such difference could result from the treatments (soaking, dehulling, and drying) that underwent the bean for obtaining the flour or by differences in the milling process. BD influences both the textural properties of food and the packaging specifications of flour and is particularly significant in the preparation of weaning food formulations. During the cooking process of weaning foods, the gelatinization of starch produces a highly viscous matrix, which shows the best texture when it is appropriately thick and viscous in order to be easily eaten by an infant. Therefore, flours with low BD are easy digestible (Desikachar, 1980) and are suitable for the production of infant and weaning foods. However, high BD values are preferable for packing, storage, and transport because high amounts of flour occupy a limited volume.

WAI represents the weight of swollen starch after heat treatment of flour. It is related to the integrity of starch granules and to their gelation properties (Du et al., 2014). WSI, related to WAI, quantifies the amount of soluble solids remaining in the aqueous phase after flour heating. The values observed for both WAI and WSI indicate a higher presence of damaged starch—able to gelatinize easily absorbing high amounts of water and releasing amylose—in cowpea flour than in wheat flour.

WAC, determined at room temperature, directly reflects the ability of some macromolecules to bind water, such as polysaccharides and proteins (Du et al., 2014). Cowpea flour showed higher WAC than wheat flour, due to higher protein content and to the presence of damaged starch, the latter indicated by the observed values of WAI and WSI. The values of WAC observed in cowpea flour were higher than those reported in other studies (Appiah et al., 2011; Khalid & Elharadallou, 2013), probably due to differences in flour particle size, as observed by Kerr et al. (2000), indicating that cowpea milling is not perfectly standardized among different milling companies. WAC of wheat flour agreed with previous works (Kumar & Saini, 2016).

The two types of flour showed different pasting characteristics (Table 1). Starch swelling occurred at a lower temperature in cowpea than in wheat flour and produced a less viscous gel. With cooling, wheat flour showed a more marked setback, indicating a greater tendency to starch retrogradation, as observed in previous works (Mariotti, Zardi, Lucisano, & Pagani, 2005; Pasqualone et al., 2010). The results for cowpea flour were similar to those reported by other authors (Adebooye & Singh, 2008).

Proteins influence the pasting properties by reducing heat-induced swelling of starch (Dericke et al., 2005). Therefore, the lower...
peak viscosity of cowpea paste compared with wheat paste could be due to the higher protein content of cowpea flour. Another factor that concurred to lower the viscosity of cowpea paste was the higher presence of damaged starch than in wheat flour, as indicated by both WAI and WSI. Damaged starch, in fact, increases water absorbing capacity and sensibility to α-amylase and, consequently, decreases paste viscosity (Farrand, 1964). Moreover, the heat-induced cross-linking of gluten by disulfide bonds, occurring only in wheat flour, causes an increase of paste viscosity (Attenburrow, Barnes, Davies, & Ingman, 1990).

4.2 | Physicochemical properties of fritters

4.2.1 | Surface and inner color

The differences in color between ata and popizza could be explained by the highest content of damaged starch in cowpea flour, as indirectly indicated by WAI, WSI, and by viscosity measures. In fact, the combined presence of damaged starch and amylase determines an increase of reducing sugars in the food matrix that could enhance Maillard reaction with consequent browning, more marked in ata surface. The brown external color of ata has been reported also by Prin-yawiwatkul, McWatters, Beuchat, and Phillips (1994), whereas a light-colored interior has been reported to be a quality feature, as the result of perfect removal of seed coats and “black eyes” of cowpea beans (Patterson, Phillips, McWatters, Hung, & Chinnan, 2004).

4.2.2 | Crumb structure and texture, oil uptake

The structural differences between the two fritters were related to the different chemical composition and pasting properties of flours. In particular, the lack of gluten in cowpea flour was the cause of the finer crumb structure of ata compared with popizza (Figure 2). Indeed, gluten confers to the dough its typical viscoelasticity and keeps the integrity of gas cells allowing their expansion during fermentation and baking, thus resulting in a spongy crumb (Masure, Wouters, Fierens, & Delcour, 2019). Moreover, gluten network hampers the moisture loss during frying, by holding the steam inside the product and creating large cells, that contributes to a considerably spongy texture. In ata, the gas could not be easily retained by the matrix, due to both the lack of a viscoelastic gluten network and the scarce ability of the starchy fraction of cowpea flour to produce a highly viscous paste. These two conditions together caused the reduced porosity observed in ata.

The different crumb structure of the two types of fritters impacted their texture (Table 3), with denser structure corresponding to harder consistency. Hallén, İbanoğlu, and Ainsworth (2004) reported that even a partial substitution of wheat flour by cowpea flour is responsible, in bread making, for a worsening of the dough characteristics due to the absence of gluten. The dough becomes sticky and less able to retain air, resulting in harder and more compact bread. The production of batter, instead, as in these fritters, which tolerates the absence of gluten better than a more consistent dough, smoothed the textural differences between ata and popizza explaining the lack of statistical significance for many of the parameters measured.

Regarding oil uptake, it is known that during frying water migrates from the center to the surface of food and then evaporates, leading to the formation of voids and capillary pathways that cause the adhesion of oil. After frying, the temperature decreases and the absorbed oil tends to migrate from the surface to the center of the product, due to a vacuum effect caused by steam condensation (Gamble & Rice, 1987). Oil absorption is related to pore radius, with smaller pores causing higher capillary pressure and then higher oil uptake (Moreira, Sun, & Chen, 1997). Ata fritters showed a more finely porous crumb structure than popizza, and this explains why ata absorbed more frying oil. Also gluten plays a role (Gazmuri & Bouchon, 2009), because after thermal denaturation, it contributes in creating a compact external layer, reducing the oil uptake of popizza. Together with the above
reported less porous structure (Figure 2), the high oil uptake had a further detrimental effect on the specific volume of ata, which was significantly lower than in popizza.

5 | CONCLUSIONS

The evaluation of the physicochemical properties of ata and popizza and their raw flours showed that, despite ata fritters are gluten free, they showed good textural properties, not significantly different compared with those of the gluten-containing Italian popizza. Therefore, ata is a well-structured street food suitable for people with coeliac disease. However, the high oil content of these fritters, particularly that of ata, undermines a daily consumption.

Food, and in particular, the street food, can be a vehicle for sharing culture and traditions, which are strongly related to food. A strong linkage, in fact, exists between food, culture, and locality.

The obtained results could help establishing a quality record of these little studied minor productions. In particular, the findings could represent a first step towards a better knowledge of these products also outside their area of origin, as a vehicle of local culture and with potential further positive effects on local economy. To enhance the production of cowpea in a food sovereignty perspective could be the basis for achieving food security.

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CONFLICT OF INTERESTS

The authors have no conflict of interest to declare.

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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