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Sustainable innovation in pasta production: Exploring the potential use of "second cheese whey" as water substitute

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ABSTRACT

This study investigated the potential application of *scotta,* the whey-based leftover from Ricotta cheese production, as a water substitute in dry pasta production and its impact on physicochemical, textural, antioxidant and sensory characteristics of the resulting product. Two types of *scotta* were investigated, obtained as by-products of the Ricotta cheese produced using the whey leftover from the Toma Piemontese PDO and cow's milk Mozzarella cheeses production. Five pasta formulations were developed: a control sample (Ctrl, 100% water) and samples with 50% or 100% water replaced by *scotta* from Toma Piemontese PDO (T50, T100) or cow's milk Mozzarella (M50, M100) whey. Each pasta sample was evaluated for proximate composition, cooking properties, colour, texture properties, antioxidant activity and sensory characteristics and acceptability. Results showed that the *scotta* type played a critical role in shaping the overall quality characteristics of pasta. *Scotta* substitution affected cooking behaviour and increased the antioxidant properties of cooked pasta. Sensory perception, rather than instrumental texture, was the most influenced parameter. The M50 sample showed the best balance of colour, antioxidant activity and sensory characteristics, resulting the formulation suitable to enhance the nutritional and functional profile of pasta without compromising consumers' acceptability. Conversely, Toma Piemontese PDO *scotta*-based formulations led to more marked changes mainly in texture properties, including increased firmness, chewiness and adhesiveness, which negatively affected consumers' liking. Overall, this study suggested *scotta* as a sustainable ingredient that reduces dairy waste and promotes innovation in pasta production, providing a foundation for broader applications of dairy by-products in food systems.

1. Introduction

The dairy industry is among the most resource-intensive sectors within the agri-food system (Feil et al., 2020; Milani et al., 2011), generating significant volumes of by-products throughout its production processes (Ahmad et al., 2019; Sar et al., 2022). Among these, whey is one of the most prevalent, and it is produced in large volumes during cheese manufacturing (Mollea et al., 2013). Nowadays, whey is used in the production of whey powder, protein concentrates/isolates, functional bioactive ingredients, feed supplements and biotechnological products like bioethanol, bioplastics, biogas and edible film (Zandona et al., 2021). However, the cheapest method to reuse whey is for the production of whey cheeses (Albenzio & Santillo, 2024; Bintsis & Papademas, 2023). For instance, in Italy, over 9.5 million tons of whey are generated each year (Bosco et al., 2018), of which about 1 million tons are used to produce Ricotta cheese (CLAL, 2025), which is the acid-heat coagulated whey cheese (Mangione et al., 2023).

The by-product derived from Ricotta processing is the second cheese whey, also defined as *scotta*, which is the liquid fraction remaining after the coagulation of whey proteins (Bosco et al., 2018; Carvalho et al., 2013; Fancello et al., 2024). *Scotta* retains approximately 60 % of the dry matter content of the original cheese whey (Carvalho et al., 2013). However, it is also characterized by high Biochemical Oxygen Demand and Chemical Oxygen Demand values, and high salinity, thus resulting in a significant source of pollution (Carvalho et al., 2013; Pires et al., 2021). As such, its disposal presents both environmental and economic

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challenges for dairy industries (Rocchetti et al., 2025). Despite its nutritional profile, rich in lactose, minerals and bioactive components, *scotta* remains largely underutilized (Fancello et al., 2024). Previous studies have investigated its potential for the production of lactose or other antioxidant compounds (Cabizza et al., 2021; Monari et al., 2019; Monti et al., 2018; Pontonio et al., 2021; Sommella et al., 2016), as growth substrate for microorganisms (Bosco et al., 2021; Coronas et al., 2023; Naziri et al., 2023; Rocchetti et al., 2025), for production of bio-ethanol or edible films (Bosco et al., 2018; Pires et al., 2024; Sansonetti et al., 2009), or for the extraction of health-promoting compounds to be reused in food or cosmetic industries (Alfano et al., 2022). Only a few recent studies have explored its use in the production of beverages, such as sport drinks (Tirloni et al., 2020), specialty beer (Pasta et al., 2024) and fermented beverages (Mangiapelo et al., 2025; Maragkoudakis et al., 2016). To the best of our knowledge, very few studies evaluated the use of *scotta* as an ingredient in food applications. Specifically, Pires et al. (2022) evaluated the use of goat and sheep liquid second cheese whey concentrates for ice cream production, whereas Ricci et al., (2026) explored the use of second cheese whey from buffalo milk as liquid component in sourdough bread dough. These limited food applications highlight a significant gap in the literature regarding the integration of *scotta* into solid food matrices.

Meanwhile, there is an increasing demand for sustainable food production and the valorization of by-products have driven research toward the application of upcycled ingredients - defined as surplus ingredients that would have been otherwise wasted (Aschemann-Witzel et al., 2023; Bhatt et al., 2018) - in staple foods such as bread, pasta and noodle (Thorsen et al., 2022). Within a circular economy framework, this approach aims to close material loops by reintroducing food by-products into the production cycle as secondary raw materials rather than waste (DeLorenzo et al., 2019). Pasta is a globally consumed staple food, conventionally produced using durum wheat semolina and water, with Italy being the largest producer and consumer (Serventi & Sabban, 2002). However, pasta production is a water-intensive process. Although the wheat cultivation accounts for the majority of the total water footprint of pasta production, a significant portion of the blue water footprint derives from the dough-mixing stage (Ruini et al., 2013), where water is required to hydrate semolina and initiate gluten network formation (Sicignano et al., 2015). Reducing freshwater use at this stage represents a key leverage point to reduce the environmental impact of pasta within a circular economy perspective (Ruini et al., 2013). So, there is the necessity to explore strategies that minimize water consumption at every stage of pasta production (Ruini et al., 2013), including formulation and processing steps.

Therefore, considering the high-water demand in pasta production, replacing water with *scotta,* during the dough-mixing phase, may offer a promising upcycling opportunity, potentially enhancing sustainability for both dairy and pasta industries through reduced water use and by valorising a dairy by-product that otherwise poses disposal challenges, thereby aligning with circular economy principles of resource efficiency and waste reduction (European Commission, 2015).

Based on these assumptions, this study aimed at investigating the feasibility of using *scotta* as partial or total substitute for water during the dough-mixing phase of pasta production and to evaluate its impact on the physicochemical, colour, textural, antioxidant, sensory characteristics and consumers' acceptability of the resulting products.

2. Materials and methods

2.1. Pasta ingredients

Two types of *scotta* were investigated, obtained as by-product of the Ricotta cheese produced using the whey leftover from the production of two different Italian cheeses (Toma Piemontese PDO and cow's milk Mozzarella). Cow's Mozzarella (Mozzarella) *scotta* was kindly provided by Caseificio Pugliese F.lli Radicci (Lauriano, Turin, Italy) and its composition was as follows (expressed as g/100 g of product): 94.61 water, 4.27 sugar, 0.51 ash, 0.50 protein and 0.11 fat. Toma Piemontese PDO (Toma) *scotta* was kindly provided by the farm Cascina Clivia (Condove, Turin, Italy) and had a composition of 95.39 water, 2.95 sugar, 1.10 ash, 0.45 protein and 0.11 fat (expressed as g/100 g of product). The whole "high fibre" durum wheat semolina was acquired from Molino Grassi (Parma, Italy) and its composition was as follows (expressed as g/100 g of product): carbohydrate 59.00, water 13.50, protein 11.80, fibre 11.70, fat 2.40 and sugar 1.70.

2.2. Pasta production

All pasta samples were produced with whole durum wheat semolina. Five gemelli-shape pasta samples were produced (Tab. 1): the control sample (Ctrl), in which 100 % of water was used to hydrate the semolina; two samples in which 50 % of the water required to hydrate the semolina was substituted with Toma (T50) and Mozzarella (M50) *scotta,* respectively; two samples in which the water was completely substituted with the Toma (T100) and Mozzarella (M100) *scotta,* respectively.

The moisture content of pasta samples was standardized to 36 % according to the standard protocol for pasta manufacturing employed by the company. In detail, 272 mL/kg of water were added to the control pasta sample, 136 mL of water and 136 mL of *scotta* were used in the 50 % *scotta*-based pasta formulations, while 272 mL/kg of *scotta* were added into the 100 % *scotta*-based pasta formulations. The pasta-making process was performed using an industrial Monferrina P12 pasta maker (Imperia & Monferrina, Castell'Alfero, Cuneo, Italy) with a production capacity of 25–35 kg/h, equipped with a bronze extruder-die comprising 9 mm diameter holes featuring a "gemelli shape", and operating at a pressure of 95–130 atm, at a temperature of 30°C and with an extrusion speed of 2–3 mm/min. Each pasta formulation was produced as a single pilot-scale batch (30 kg). To obtain independent replicates, pasta samples were collected at three different stages of production – initial, middle and final (each counting 20 min of extrusion) - and each sample was treated as a distinct replicate. The samples were then dried in an industrial Monferrina EC/NG25 drier for 15 hours, utilising a low-temperature drying programme (T max=40°C) and a linear decrease in relative humidity from 80 % to 10 % within the drier chamber throughout the entire process. The whole wheat dry pasta was produced at the Ferrari Specialità Alimentari Company (Cherasco, Cuneo, Italy).

2.3. Proximate analyses

The proximate components of uncooked pasta samples were determined using standard analytical procedures. Ash, crude fat, crude fibre, moisture and protein content were measured according to AOAC methods 923.03, 925.12, 985.29, 925.09 and 960.52, respectively (AOAC, 2000). Sugar content was determined according to AACC method 80–04.01 (AACC, 1999). The carbohydrate value was determined by difference: [100 - (% ash + % fat + % fibre + % moisture + % protein)].

Table 1
Liquid types and concentrations used during the production of whole wheat pasta samples.

Pasta sample	Water	*Scotta*	
		Concentration (%)	Type
Ctrl	100	0	-
M50	50	50	Mozzarella
M100	0	100	
T50	50	50	Toma
T100	0	100	

2.4. Colour analysis

The colour parameters L*(lightness, where 0 correspond to black and 100 to white), a* (which measures the redness or greenness - when respectively positive or negative) and b* (which indicates the yellowness or blueness - when respectively positive or negative) of both the uncooked and cooked samples were measured using a CM-5 spectrocolorimeter (Konica Minolta, Tokyo, Japan) on transmittance with a measurement area of 3 mm, an angle of observation of 10°, an illuminant D65, a wavelength spectrum between 360 and 740 nm, and in Specular Component Excluded mode. The determinations were conducted in triplicate. The CIE L*a*b* parameters were additionally used to calculate the total difference between two colours (ΔE*) applying the formula reported in Eq. (1):

$$\Delta E_{Lab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{Eq. 1}$$

ΔE* values were calculated to relate instrumental colour measurements to human visual perception. Indeed, according to International Commission on Illumination recommendations (CIE, 1978), ΔE values can be used to estimate whether colour differences are likely to be noticeable by an observer (consumer). Indeed, colour is one of the most easily and rapidly evaluated sensory attributes, strongly influencing pasta choice and expectations of taste and quality, and large colour shifts (high ΔE values), being clearly visible, can either arouse curiosity or alter consumers' liking (Duda et al., 2019; Teterycz et al., 2019). In accordance with the findings reported by Mokrzycki & Tatol (2011), values ranging from 2 to 3.5 on the ΔE scale indicate that an unskilled observer is likely to discern the discrepancy in colour, while a discernible difference in colour is evident at values exceeding 3.5 on the ΔE* scale.

2.5. Cooking pasta quality

2.5.1. Optimum cooking time

The analysis was performed by the visual AACC method 66–50.01 (AACC, 1999). For the cooking process, the pasta was immersed in distilled boiling water (pasta:water ratio of 1:10) without the addition of salt and without interruption to the boiling process. At 30 s intervals, a single sample was collected and immediately subjected to compression between two glass plates. The optimum cooking time (OCT) corresponded to the time required for the disappearance of the starchy white core. The determinations were conducted in triplicate.

2.5.2. Water adsorption

To estimate the water absorption (WA), 10.0 g of dry pasta (w0) was cooked at its OCT in 100 mL of distilled boiling water and, after the water drained off, the cooked pasta weight (w1) was recorded (Nocente et al. 2021). The determinations were conducted in triplicate. The WA was calculated using the Eq. (2):

$$Water\ adsorption\ (\%) = \frac{w1 - w0}{w0} x\ 100 \tag{Eq.2}$$

2.5.3. Cooking loss

The cooking loss (CL) - the dry matter leached during the cooking process - was measured by cooking 10.0 g of dry pasta at its OCT in 100 mL of distilled boiling water. Following the cooking process, the pasta was drained and rinsed with 100 mL of distilled water. The water used for cooking and rinsing was collected in a beaker and evaporated at 105 ± 1°C in an air oven until constant weight of the residue was reached (Nocente et al. 2021). The determinations were conducted in triplicate. The data were expressed as grams of dry matter loss per 100 g of raw pasta. The CL was calculated using Eq. (3):

$$Cooking\ loss\ (\%) = \frac{weight\ of\ cooking + rinsed\ water\ residue}{weight\ of\ dry\ pasta} x\ 100 \tag{Eq.3}$$

2.6. Texture profile analysis

Each pasta sample was cooked at its OCT, using the ratio pasta:water of 1:10. The pasta samples were rinsed with cold water for two minutes after cooking to prevent overcooking. Then, after resting for five minutes at room temperature, they were subjected to texture analysis. The texture analyzer (TA.HD *Plus* C; Stable Micro System, Surrey, UK) was equipped with a 10 kg load cell. To record data, Exponent software (version 8.1.6.0) was used. All texture measurements were carried out in twelve replicates, by adapting the procedure of the Texture Profile Analysis (TPA) reported in El-Sohaimy et al. (2020). The texture parameters evaluated were: hardness (N), springiness (%), cohesiveness (adimensional), gumminess (N), chewiness (N·s) and resilience (adimensional). The instrument was equipped with a P100 compression plate, with default settings of 1 mm/s pre-test speed, 2 mm/s test speed and 5 mm/s post-test speed, 75 % strain, trigger force of 5 g and 400 points per second (pps) data acquisition.

2.7. Total phenolic content and in vitro antioxidant activity

2.7.1. Extraction of phenolic compounds

Pasta samples (both uncooked and cooked) were lyophilised (Lio5P, Cinquepascal, Trezzano sul Naviglio, Milan, Italy) and milled to a particle size of 250 µm using an ultra-centrifugal mill ZM 200 (Retsch GmbH, Haan, Germany). The phenolic compounds were extracted using the method reported by Zeppa et al. (2015) with some modifications. Briefly, samples of pasta (1 g) were extracted twice with 10 mL of a methanol and water solution acidified with formic acid at pH 2 (80:20 v/v) in dark conditions with regular shaking for 2 h. After centrifugation (16 800 x g, 15 min, 5°C), the supernatants were collected, filtered (0.45 µm PTFE) and stored in amber vials at -20°C until analyses were performed. All samples were extracted and assessed in triplicate.

2.7.2. Total phenolic content assay

The total phenolic content (TPC) of the extracts was evaluated according to the Folin-Ciocalteu method described by Singleton et al. (1999). The measurements were conducted using a 96-well BioTEx Synergy HT spectrophotometer multi-detection microplate reader (BioTex Instruments, Milan, Italy). The sample extracts (20 µL) were dispensed into the corresponding wells of a microtiter plate, each containing 100 µL of tenfold-diluted Folin-Ciocalteau aqueous reagent. Following gentle mixing and a 3 min incubation, 75 µL of a 7.5 % sodium carbonate anhydrous solution were added to each well. The mixtures were then homogenized again and incubated for 1 hour at 25°C in the dark. The absorbances were recorded at 740 nm against a reagent blank. For quantitative purpose, an analytical curve was prepared using gallic acid as a stable phenolic compound (100 – 500 µM). The results were expressed as mg gallic acid equivalent (GAE) per g of dry weight (dw).

2.7.3. Radical scavenging assay

The 1,1-diphenyl-2-picrylhydrazyl (DPPH$^{\bullet}$) free radical scavenging activity (RSA) was determined according to the method of von Gadov et al. (1997) with some modification and adapted to a microplate reader. Twenty microliters of the extract were added to 180 µL of DPPH• solution (120 µM in 80 % ethanol) in the wells of a microplate. The mixture was shaken, covered and incubated in the dark for 30 min at 25°C. The decrease in DPPH• absorbance was measured at 517 nm against a reagent blank, and the radical inhibition percentage (IP) was calculated according to the Eq. (4):

$$IP = \frac{(A_0 - A_{30})}{A_0} \times 100 \quad \text{(Eq.4)}$$

Where A_0 is the absorbance at initial time and A_{30} is the absorbance at 30 min.

Trolox was used as a standard (12.5–300 μM) to construct a calibration curve. The results were expressed as μM of Trolox equivalent (TE) per g of dry weight (dw).

2.8. Sensory analysis

2.8.1. Participants

Participants (n = 107, females = 63 %, age range = 18–57, mean age: 28.7 ± 9.9) were recruited among the students and staff of the University of Gastronomic Sciences (UNISG, Pollenzo, Italy). They voluntarily participated in the study and signed a written informed consent before performing the sensory evaluation. The study was conducted in accordance with the ethical guidelines of the Declaration of Helsinki and received approval from the Ethics Committee of UNISG (Ethics Committee Proceedings n. 05.2024). The majority of participants were Italian (52.3 %), omnivores (75.7 %) and showed high familiarity with pasta, with 55.1 % reporting pasta consumption more than twice a week and 43.9 % consuming whole wheat pasta at least once a month. Therefore, the whole-wheat pasta consumption frequency reported by participants was consistent with Italian consumer trends (Ruggiero et al., 2019). Although whole-wheat pasta is still consumed less frequently than conventional pasta, recent studies indicated a growing consumers' interest in whole-grain cereal products, including pasta, due to their recognised health benefits (Altamore et al., 2020; Marti et al., 2017). For this reason, whole-wheat pasta was selected as the product model for this study, as it represents an increasingly relevant segment in the Italian pasta market (Altamore et al., 2020).

The complete sociodemographic profile and information related to consumption behaviour of participants are reported in Supplementary materials (Tab. S1).

2.8.2. Pasta preparation and serving conditions

For the cooking procedure, the ratio of 100 g of pasta in 1 L of water with 8 g of salt added was maintained for each pasta formulation. To ensure consistency in sensory evaluation, each sample was cooked at its own optimum cooking time, previously determined. To guarantee consistent serving temperature and doneness, pasta samples were cooked in distinct batches and evaluated immediately after draining, within approximately one minute, including oil addition, plating and serving. The five samples were served in two sets during each session (3 + 2 samples), with the serving order randomized across sessions. In some sessions, the first set included Ctrl, T50 and M50, and the second included T100 and M100, whereas in other sessions this order was inverted. The second set was cooked while participants evaluated the first set, avoiding texture changes due to waiting time. After cooking and draining, pasta samples were seasoned with 10 g of corn oil per 100 g of pasta, according to Laureati et al. (2016). Approximately 20 g of pasta per sample were served monadically on paper plates labelled with three-digit random codes, in a random order generated using a Latin square design through FIZZ software version 2.47b (Biosystèmes, Courtenon, France).

2.8.3. Evaluation procedure

Sensory evaluation was performed at the Sensory, Behavior and Cognition laboratory at UNISG, in individual computerized booths under white light, in a room temperature of approximately 22 ± 2°C. For each of the five samples, participants were first asked to rate their overall liking and liking for all the sensory modalities (appearance, odour, taste, flavour, texture), using a nine-point hedonic scale (1 = dislike extremely, 9 = like extremely) (Peryam & Pilgrim, 1957). Then, participants were asked to select all the sensory terms they considered appropriate for describing the pasta samples, choosing from a list of 18 attributes related to appearance (yellow colour, brown colour, sticky), flavour (raw cereal, wheat, lactic), taste (sweet, salty, bitter, sour, umami), and texture (grainy, firm, amassment, adhesive, homogeneous, elastic, chewy). The sensory attributes were selected from previous studies on whole wheat pasta (Pagliarini et al., 2012; Škrobot et al., 2022) and by a previous benchtop tasting. Then, participants rated the intensity of the selected terms, according to the methodology of the Rate-All-That-Apply (RATA) test (Ares et al., 2014) and by using a general Labelled Magnitude Scale (ranging from "not perceptible at all" to "the strongest you can imagine") (Green et al., 1993). Consumers received the full list of sensory attributes accompanied by their corresponding definitions (Tab. S2). Still water was provided for palate cleansing between samples, following a rinsing protocol lasting 45 s. After the sensory evaluation, participants answered the question: "*How appropriate is, in your opinion, the use of scotta - a by-product of ricotta production process - as substitute for water in the dough-mixing phase of dry pasta production?*". The level of appropriateness was rated on a seven-point scale (1 = completely inappropriate; 7 = completely appropriate) (Cela et al., 2025). Therefore, the appropriateness question was intended to assess the consumers' attitude toward the use of a dairy by-product in pasta production, thus exploring the consumers' general perception about the valorization of by-products according to circular economy principles. Then, participants indicated their willingness to buy a *scotta*-based pasta (1 = definitely no; 7 = definitely yes). Finally, participants provided their sociodemographic characteristics and frequency of consumption of both pasta and whole wheat pasta (Palmieri et al., 2021).

2.9. Statistical analysis

The data related to proximate composition, colour, cooking quality parameters, TPA and in vitro antioxidant activity were analyzed using one-way analysis of variance (ANOVA), followed by Tukey's post-hoc test at a fixed level of α=0.05 to identify differences among the samples. A correlation analysis using the two-tailed Pearson correlation coefficient was performed to determine the correlation between the variables. Liking scores were analyzed using a two-way ANOVA (fixed factor: sample; random factor: participant) followed by Tukey's post-hoc test. For intensity scores from the RATA test, a value of "0" was assigned to those sensory attributes not selected by participants. Mean scores of parameters showing significant differences among samples were considered as active variables of Multiple Factor Analysis (MFA), performed to visualize relationships between proximate composition (three variables), cooking quality parameters (two variables), antioxidant properties (two variables), colour parameters (one variable) and sensory attributes (nine variables) of pasta samples. Therefore, TPA parameters were excluded from MFA since showed no significant differences among samples. Moreover, the liking scores were added as supplementary variables. All statistical analyses were performed using XLSTAT Premium Software (Version 2020.3.1, Addinsoft, Paris, France).

3. Results and discussion

3.1. Physicochemical analyses

3.1.1. Uncooked pasta

The proximate composition of the uncooked pasta samples (Tab. 2) showed that the water substitution with *scotta* significantly influenced the moisture, ash and sugar content of the pasta samples ($p < 0.05$).

The 100 % *scotta*-based pasta samples exhibited significantly higher moisture content compared to both the control and 50 % substitution samples. Considering the equal drying conditions across all samples, this increase may be attributable to the higher water-binding capacity of hydrophilic molecules such as lactose, soluble peptides and denatured proteins present in the *scotta* (Madureira et al., 2010; Wijayasinghe

Table 2
Proximate composition of the uncooked pasta samples.

Parameter	*Scotta* type	*Scotta* substitution 0 %	50 %	100 %	*p-value*
Moisture (%)	Mozzarella	9.89 ±0.06^{b}	10.27 ±0.29^{b}	11.34 ±0.02^{a,B}	*0.007*
	Toma	9.89 ±0.06^{c}	11.03 ±0.15^{b}	11.56 ±0.04^{a,A}	*<0.001*
	p-value		*0.080*	*0.024*	
Protein (g/100 g dw)	Mozzarella	13.91 ±0.38	13.76 ±0.23	13.86 ±0.47	*0.915*
	Toma	13.91 ±0.38	13.81 ±0.30	13.90 ±0.48	*0.963*
	p-value		*0.851*	*0.949*	
Fat (g/100 g dw)	Mozzarella	3.00 ±0.31	2.93 ±0.23	2.98 ±0.32	*0.970*
	Toma	3.00 ±0.31	2.94 ±0.23	2.99 ±0.32	*0.974*
	p-value		*0.972*	*0.972*	
Carbohydrates (g/100 g dw)	Mozzarella	67.35 ±1.21	67.62 ±1.02	67.56 ±1.32	*0.973*
	Toma	67.35 ±1.21	67.44 ±1.03	67.16 ±1.35	*0.972*
	p-value		*0.878*	*0.793*	
Ash (g/100 g dw)	Mozzarella	1.95 ±0.02^{b}	2.03 ±0.03^{b}	2.14 ±0.02^{a,B}	*0.012*
	Toma	1.95 ±0.02^{c}	2.16 ±0.04^{b}	2.44 ±0.02^{a,A}	*<0.001*
	p-value		*0.062*	*0.006*	
Fibre (g/100 g dw)	Mozzarella	13.79 ±0.54	13.67 ±0.59	13.45 ±0.55	*0.839*
	Toma	13.79 ±0.54	13.65 ±0.53	13.51 ±0.57	*0.881*
	p-value		*0.981*	*0.928*	
Sugar (g/100 g dw)	Mozzarella	1.95 ±0.02^{c}	2.83 ±0.04^{b,A}	3.96 ±0.02^{a,A}	*<0.001*
	Toma	1.95 ±0.02^{c}	2.56 ±0.03^{b,B}	3.34 ±0.01^{a,B}	*<0.001*
	p-value		*0.016*	*<0.001*	

Data are expressed as mean ± standard deviation.
Values in each row having different lowercase letters are significantly different (Tukey's post-hoc test, p<0.05).
Values in each column having different uppercase letters are significantly different (Tukey's post-hoc test, p<0.05).
dw= dry weight.

et al., 2015). Considering the type of *scotta*, T100 exhibited higher moisture content than M100 ($p < 0.05$), which can be explained by the 1 % higher content of water in the Toma *scotta* compared to the Mozzarella one.

Regarding the ash content, in the case of the Mozzarella *scotta*-based pasta samples, M100 showed statistically higher ash content than both M50 and Ctrl ($p < 0.05$), indicating that the extent of mineral incorporation was directly related to the proportion of *scotta* used. On the other hand, in the case of Toma *scotta*-based samples, even a partial water substitution (T50) resulted in a significant increase in ash content compared to Ctrl, suggesting that by increasing the concentration of Toma *scotta* resulted in increased ash content of the final pasta sample. Moreover, T100 showed significantly higher ash content than M100, likely due to a greater mineral content present in the Toma *scotta* than in the Mozzarella one.

Sugar content also increased proportionally with the concentration of *scotta* inclusion: M100 showed a 50 % increase in sugar content compared to Ctrl, while T100 exhibited a 42 % increase ($p < 0.05$). Moreover, across both 50 % and 100 % substitution concentrations, Toma *scotta*-based pasta samples showed significantly lower sugar content than their Mozzarella counterparts ($p < 0.05$). Therefore, these results reflected the different composition of the two *scotta* types and the higher sugar content in the Mozzarella *scotta*. Indeed, the observed increase in ash and sugar content in *scotta*-based pasta formulations compared to the control sample can be attributed to the compositional differences in the *scotta* itself, which are influenced by the cheese-making processes (different temperature, pH, starter cultures and lactose metabolism) from which they derive (Gobbetti et al., 2018).

The results of colour measurements, total phenolic content and antioxidant activity analyses on uncooked pasta are summarized in Table 3. Significant differences were observed in the L* and a* colour parameters and RSA among the Mozzarella *scotta*-based samples and between the two pasta samples made with the two *scotta* types used at 50 % substitution ($p < 0.05$). The incorporation of Mozzarella *scotta* resulted in a significant increase in pasta lightness (L*) in M50, which was significantly lighter than the control ($p < 0.05$). This effect was likely associated with the higher content of soluble whey proteins, lactose and minerals in Mozzarella *scotta*, which may had formed a brighter surface layer (Bouziane et al., 2024). Conversely, in terms of the red-green colour component (a*), a significant decrease was observed in the Mozzarella *scotta*-based samples. In Toma *scotta*-based samples, the inclusion of *scotta* did not significantly modify the a* values compared to the Ctrl ($p > 0.05$). This decrease in a* values was probably due to the presence of lactochrome pigments (riboflavin and related compounds) in the *scotta,* which typically exhibit greenish-yellow hues and may interfere with the red tones of the semolina base (Mangiapelo et al., 2025). A significant difference in a* value was also observed according to *scotta* type, with T50 having a higher a* value than M50 ($p < 0.05$), suggesting compositional differences between the two *scotta* types in pigment content or stability. Concurrently, when evaluating the total colour variation, it was observed that ΔE values greater than 5 were obtained when comparing the control with both types of *scotta* at each percentage of use (Tab. S3) demonstrating the evident colour change. However, a value of 3.1 was obtained when the two types of *scotta* were compared with each other, suggesting a noticeable but less pronounced

Table 3
Colour parameters (L* - lightness, a* - redness, b* - yellowness), total phenolic content (TPC) and radical-scavenging activity (RSA) value of the uncooked pasta samples.

Parameter	*Scotta* type	*Scotta* substitution 0 %	50 %	100 %	*p-value*
L*	Mozzarella	68.22 ±5.14^{b}	76.06 ±0.10^{a,A}	75.54 ±0.69^{a,b}	*0.032*
	Toma	68.22 ±5.14	73.10 ±1.17^{B}	72.39 ±3.24	*0.271*
	p-value		*0.012*	*0.174*	
a*	Mozzarella	5.54 ±1.20^{a}	3.69 ±0.04^{b,B}	3.97 ±0.25^{a,b}	*0.038*
	Toma	5.54 ±1.21	4.46 ±0.24^{A}	4.34 ±0.73	*0.227*
	p-value		*0.005*	*0.452*	
b*	Mozzarella	18.57 ±2.05	15.44 ±0.52	16.28 ±0.72	*0.058*
	Toma	18.57 ±2.05	16.42 ±0.67	15.77 ±1.63	*0.150*
	p-value		*0.115*	*0.646*	
TPC mg GAE/g (dw)	Mozzarella	1.92 ±0.02	1.91±0.01	1.94 ±0.02	*0.195*
	Toma	1.92 ±0.02	1.92±0.03	1.86 ±0.07	*0.298*
	p-value		*0.767*	*0.136*	
RSA μM TE/g (dw)	Mozzarella	0.31 ±0.01^{b}	0.37 ±0.01^{a,A}	0.31 ±0.04^{a,b}	*0.045*
	Toma	0.31 ±0.01	0.29 ±0.00^{B}	0.29 ±0.01	*0.090*
	p-value		*<0.001*	*0.478*	

Data are expressed as mean ± standard deviation.
Values in each row having different lowercase letters are significantly different p<0.05, according to Tukey post-hoc test.
Values in each column having different uppercase letters are significantly different p<0.05, according to Tukey post-hoc test.
GAE = gallic acid equivalent; TE = Trolox equivalent.

difference.

In this study, the RSA of *scotta*-based pasta samples showed distinct patterns depending on the *scotta* type. M50 demonstrated the highest value in RSA among all samples, with a significant increase compared to the control ($p < 0.05$). On the other hand, both Toma *scotta*-based samples exhibited RSA values that were not significantly different from the Ctrl ($p > 0.05$). Overall, the increase in antioxidant activity observed in *scotta*-based pasta samples, particularly those containing Mozzarella *scotta,* could be attributed to the presence of bioactive compounds such as peptides and residual milk-derived antioxidants (Madureira et al., 2010; Tavares & Malcata, 2013). Indeed, previous studies demonstrated that *scotta* can be valorised through biotechnological approaches to release peptides with biological activities, such as antioxidant and ACE-inhibitory effects (Monari et al., 2019; Pontonio et al., 2021). In addition, peptidomic analyses further confirmed the presence of numerous bioactive peptides in *scotta* with potential health benefits (Sommella et al., 2016), thus considering *scotta* as a valuable substrate for producing functional ingredients (Cabizza et al., 2021). Moreover, the protein fraction of *scotta* also showed antibacterial peptides, as confirmed by Monari et al. (2019). In addition, the antioxidant activity of *scotta*-based pasta may also be influenced by residual sulphur-containing amino acids and bioactive peptides, which are present in high proportions in whey proteins and are known to exert antioxidant and immunomodulatory functions (Anand et al., 2013; Sumny & Kempka, 2025). Furthermore, the lactose present in milk and consequently in whey, as a consequence of the elevated temperatures employed in Ricotta production processes, participates in Maillard reactions, forming antioxidants (melanoidins) that increase the antioxidant capacity (Stobiecka, Król & Brodziak, 2022). Therefore, findings from this study confirmed that *scotta* can act not only as a water substitute in pasta-making but also as a functional ingredient contributing to the added nutritional value of the final product. Images of uncooked pasta samples are provided in Supplementary materials (Fig. S1).

3.1.2. Cooked pasta

Table 4 shows the cooking quality parameters, colour characteristics, total phenolic content and antioxidant capacity of the five cooked pasta samples. Images of cooked pasta samples are provided in Supplementary materials (Fig. S2).

Mozzarella *scotta*-based pasta samples showed statistically longer OCT compared to those made with Toma *scotta*, at both 50 % and 100 % substitution levels ($p < 0.05$). This result could be attributed to the lower moisture content in the uncooked Mozzarella *scotta*-based pasta formulations. Indeed, the lower the moisture content in uncooked pasta, the longer the time needed for water to fully penetrate and hydrate the pasta and for the starch to fully swell and gelatinize (Cunin et al., 1995; Hwang et al., 2022), thereby delaying complete cooking.

The WA was significantly affected by the inclusion of *scotta* at both concentrations of substitution ($p < 0.05$), regardless of the *scotta* type ($p > 0.05$). In general, samples incorporating *scotta* exhibited a reduced WA compared to Ctrl ($p < 0.05$). A significant negative correlation was found between WA and moisture content ($r^2 = -0.775$; $p < 0.05$), supporting the hypothesis that higher internal water content reduced the pasta's capacity to absorb external water during cooking. This could be due to the gelatinization and swelling of the starch in the outer layer upon cooking, forming a barrier that blocks further water diffusion into the inner starch layers and limits additional water adsorption, a phenomenon called "gel blocking" (Toultchinski & Vilgis, 2024).

The inclusion of *scotta* in pasta production did not alter the cooking loss of pasta samples ($p > 0.05$). Nonetheless, the CL showed a statistically significant negative correlation with the moisture content ($r^2 = -0.772$; $p < 0.001$). This suggested that the higher water content of the sample may have facilitated the formation of a robust gluten network, thus allowing solid retention inside the starch-protein structure, thereby preventing the dissolution of the starch and other constituents in the cooking water (Diamante et al., 2019).

Table 4
Optimum cooking time (OCT), water absorption (WA), cooking loss (CL), colour parameters (L* - lightness, a* - redness, b* - yellowness), total phenolic content (TPC) and radical-scavenging activity (RSA) value of the cooked pasta samples.

Parameter	*Scotta* type	*Scotta* substitution 0 %	50 %	100 %	*p-value*
OCT (min)	Mozzarella	5.00 ±0.38	5.00 ±0.43^{A}	5.00 ±0.33^{A}	*1.00*
	Toma	5.00 ±0.38^{a}	4.00 ±0.41^{b,B}	4.00 ±0.35^{b,B}	*<0.001*
	p-value		*<0.001*	*<0.001*	
WA (%)	Mozzarella	104.50 ±0.75^{a}	95.74 ±4.49^{b}	95.62 ±1.39^{b}	*0.011*
	Toma	104.50 ±0.75^{a}	93.67 ±5.69^{b}	94.00 ±2.65^{b}	*0.017*
	p-value		*0.646*	*0.402*	
CL (%)	Mozzarella	4.65 ±0.68	3.94 ±0.30	3.56 ±0.20	*0.060*
	Toma	4.65 ±0.68	3.67 ±0.28	3.91 ±0.45	*0.117*
	p-value		*0.092*	*0.081*	
L*	Mozzarella	59.72 ±0.58^{c}	63.71 ±0.02^{a,A}	61.78 ±1.81^{b}	*<0.001*
	Toma	59.72 ±0.58^{b}	62.81 ±0.24^{a,B}	63.14 ±0.36^{a}	*<0.001*
	p-value		*0.003*	*0.084*	
a*	Mozzarella	6.11 ±0.19	5.68 ±0.31	5.80 ±0.02	*0.103*
	Toma	6.11 ±0.19	5.90 ±0.12	5.58 ±0.57	*0.263*
	p-value		*0.317*	*0.548*	
b*	Mozzarella	21.92 ±0.80	21.78 ±0.51	21.50 ±0.50	*0.712*
	Toma	21.92 ±0.80	21.33 ±0.45	21.84 ±0.73	*0.549*
	p-value		*0.313*	*0.538*	
TPC mg GAE/ g (dw)	Mozzarella	1.40 ±0.00^{b}	1.38 ±0.01^{b,B}	1.46 ±0.01^{a}	*<0.001*
	Toma	1.40 ±0.00	1.43 ±0.02^{A}	1.44 ±0.03	*0.159*
	p-value		*0.022*	*0.432*	
RSA µg TE/g (dw)	Mozzarella	0.27 ±0.01^{b}	0.32 ±0.02^{a,A}	0.31 ±0.00^{a,A}	*0.014*
	Toma	0.27 ±0.01^{a}	0.25 ±0.00^{b,B}	0.27 ±0.01^{a,b,B}	*0.033*
	p-value		*0.004*	*<0.001*	

Data are expressed as mean ± standard deviation.
Values in each row having different lowercase letters are significantly different $p<0.05$, according to Tukey post-hoc test.
Values in each column having different uppercase letters are significantly different $p<0.05$, according to Tukey post-hoc test. GAE = gallic acid equivalent; TE = Trolox equivalent.

As for the colour parameters, the use of *scotta* as water substitute significantly influenced only the lightness of the cooked pasta samples ($p < 0.05$). In pasta products, lightness is strongly influenced by the presence of coloured pigments, which tend to decrease reflectance and reduce L* values (Cavazza et al., 2013; Sharma et al., 2025). As previously observed for the uncooked pasta, the *scotta* employment resulted in an enhancement of lightness compared to Ctrl ($p < 0.05$) due to changes in surface reflectance caused by soluble dairy solids, rather than a reduction in pigment content (Sharma et al., 2025). In Toma *scotta*-based samples, a linear increase in L* was observed between 50 % and 100 % substitution concentrations, whereas in the case of Mozzarella *scotta*-based samples, the highest lightness was recorded in M50. These changes were consistent with the previously observed lightening effect in uncooked samples and may be due to the milk solids and whey-derived components that contribute to a brighter surface appearance after cooking, aligning with previous studies that showed that the addition of whey protein isolate significantly increased the luminosity of pasta surfaces compared to control pasta sample produced with water alone, but no effect on a* parameter was observed (Bouziane et al., 2024). The total colour variation (ΔE*) between samples in the case of cooked pasta was significantly reduced, with values ranging from 1.03 to 4.02 (Tab. S3). These prompts variances were discernible in Mozzarella samples at both *scotta* concentrations, while in the case of Toma, it was only evident at the 50 % substitution.

The total phenolic content was significantly affected by the total substitution of the water with Mozzarella *scotta* ($p < 0.05$). Consequently, the antioxidant activity also significantly increased ($p < 0.05$), but already at the concentration of 50 % (M50). This higher polyphenol content may be explained by the lower water absorption and reduced cooking loss in the *scotta*-enriched samples, preserving the retention of the water-soluble antioxidant compounds originally present in the samples. Although Ctrl and T50 samples showed comparable total phenolic content after cooking, the RSA of T50 was significantly lower than Ctrl ($p < 0.05$). This behaviour may be related to the different biochemical composition of Toma *scotta*, which may contain lower levels of heat-stable antioxidant peptides compared to Mozzarella *scotta*.

3.2. Texture parameters

Texture is an important quality attribute of pasta, and it is known to be strongly influenced by both protein content and quality, particularly by the strength of the gluten network. The development of a proper gluten matrix is also dependent on the interaction between water and gluten-forming proteins during the dough mixing and hydration phases (Carini et al., 2012). The use of *scotta* as water substitute introduces a variety of components, such as proteins, organic acids, salts, minerals, lactose, which may have the potential to interact with the semolina matrix during mixing. These interactions could influence the gluten network development, a critical factor in determining pasta texture and resistance to structural degradation during cooking (D'Egidio et al., 1990; Larrosa et al., 2016). Moreover, as described by Bresciani et al. (2022), proper gluten network formation is essential to control starch swelling during cooking maintaining product structure. However, this process is strongly influenced by the dough recipe. For instance, salt, a component also present in *scotta*, has been shown to delay gluten hydration and network formation (Ooms & Delcour, 2019). Hence, given the protein content and the presence of other compounds in *scotta*, it can be hypothesized that its use as a water substitute during the dough-mixing step might impact the mechanical properties of the resulting pasta. Contrarily, TPA results on pasta samples did not show statistically significant differences ($p > 0.05$) among all samples in any of the measured texture parameters (Tab. 5). A possible explanation for this result may lie in the composition of *scotta* itself. Probably, the mineral content of *scotta* did not interfere with gluten development to a degree that would compromise the physical integrity of the cooked pasta. Additionally, the *scotta* protein content may have contributed positively to the gluten network development, by partially supporting the structural matrix.

3.3. Sensory characteristics and consumers' acceptability

Sensory characteristics are among the first criteria considered by consumers when evaluating pasta (Altamore et al., 2020). Sensory results (Tab. 6) showed that all *scotta*-based samples resulted acceptable (mean overall liking scores above five on the nine-point hedonic scale), except for T50, which received a significantly lower mean score than the other samples ($p < 0.05$). Significant differences among samples were observed in terms of liking for taste, flavour, texture and overall liking ($p < 0.05$). In particular, T50 received the lowest mean scores for all the aforementioned parameters. The most pronounced decrease in liking was observed for the texture attribute, where the mean score of T50 was 1.4 points lower than that of Ctrl. This suggested that the partial substitution of water with Toma *scotta* negatively affected the perceived sensory textural quality of the pasta, ultimately contributing to its lower overall liking. Indeed, texture is widely recognized as a key driver of pasta quality, influencing consumers' acceptability (Altamore et al., 2017). Sample M50 consistently received higher liking scores than T50 across all sensory modalities ($p < 0.05$). However, this difference was not observed between M100 and T100. Therefore, Mozzarella *scotta* appeared more suitable for preserving consumers' acceptability, particularly in formulations using 50 % water substitution.

Results from the RATA test (Table 7) showed significant differences ($p < 0.05$) among samples for nine sensory attributes (brown colour, raw cereal, salty, grainy, firm, amassment, adhesive, elastic and chewy) out of the 18 evaluated. T50 was characterized by significantly higher intensity of brown colour and raw cereal flavour perception compared to all other samples ($p < 0.05$). Although instrumental colour analysis showed a slightly higher L* value for T50, consumers perceived this sample as having a more pronounced brown colour. The discrepancy

Table 5
Texture parameters of pasta samples.

Parameter	*Scotta* type	*Scotta* substitution 0 %	50 %	100 %	*p-value*
Hardness (N)	Mozzarella	27.27 ±3.52	27.43 ±5.28	28.08 ±4.71	*0.866*
	Toma	27.27 ±3.52	27.96 ±5.26	26.94 ±6.48	*0.817*
	p-value		*0.751*	*0.572*	
Springiness (%)	Mozzarella	84.31 ±5.36	82.80 ±6.03	83.69 ±4.73	*0.737*
	Toma	84.31 ±5.36	82.69 ±7.37	83.52 ±6.46	*0.656*
	p-value		*0.962*	*0.740*	
Cohesiveness (-)	Mozzarella	0.37 ±0.07	0.38 ±0.05	0.39 ±0.09	*0.819*
	Toma	0.37 ±0.07	0.39 ±0.07	0.41 ±0.06	*0.275*
	p-value		*0.884*	*0.392*	
Gumminess (N)	Mozzarella	10.24 ±2.53	10.63 ±2.80	10.69 ±2.57	*0.870*
	Toma	10.24 ±2.53	10.25 ±2.26	10.94 ±2.86	*0.671*
	p-value		*0.633*	*0.802*	
Chewiness (N·s)	Mozzarella	8.63 ±2.59	8.78 ±2.36	8.96 ±2.38	*0.927*
	Toma	8.63 ±2.59	8.67 ±2.52	8.99 ±2.05	*0.909*
	p-value		*0.891*	*0.975*	
Resilience (-)	Mozzarella	0.30 ±0.02	0.30 ±0.04	0.32 ±0.04	*0.305*
	Toma	0.30 ±0.02	0.28 ±0.05	0.30 ±0.04	*0.289*
	p-value		*0.133*	*0.268*	

Table 6
Liking scores (mean ± standard deviation) of pasta samples.

Sample	Appearance	Odour	Taste	Flavour	Texture	Overall Liking
Ctrl	5.6±1.7	5.6 ±1.6	5.5 ±1.9 [a]	5.5±1.9 [a]	5.5±1.9 [a]	5.7±1.7 [a]
M50	5.9±1.6	5.7 ±1.5	5.6 ±1.7 [a]	5.4±1.8 [a]	5.2±1.9 [ab]	5.6±1.6 [a]
M100	5.7±1.9	5.7 ±1.6	5.6 ±1.9 [a]	5.4±1.9 [a]	4.7±2.0 [c]	5.5±1.7 [a]
T50	5.6±1.7	5.5 ±1.6	5.0 ±1.7 [b]	4.9±1.8 [b]	4.1±1.9 [d]	4.8±1.6 [b]
T100	5.8±1.8	5.7 ±1.7	5.6 ±1.9 [a]	5.6±1.9 [a]	5.1±2.0 [bc]	5.5±1.8 [a]
p-value	*0.193*	*0.572*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*

Different letters in the same column indicate significant differences (Tukey post-hoc test, $p < 0.05$).
Samples identification is reported in Table 1.

Table 7
Intensity mean values of Rate-All-That-Apply sensory attributes of pasta samples.

Attributes	Ctrl	M50	M100	T50	T100	*p-value*
Yellow colour	2.65	2.95	2.08	2.37	2.65	0.353
Brown colour	26.67^{b}	25.08^{b}	24.33^{b}	29.88^{a}	26.84^{b}	**0.004**
Sticky	9.47	12.69	11.50	11.52	11.79	0.407
Raw cereal	20.45^{c}	21.46^{bc}	23.89^{b}	27.80^{a}	21.80^{bc}	**< 0.001**
Wheat	24.33	24.73	26.01	27.95	26.30	0.303
Lactic	2.94	3.93	3.50	3.97	3.72	0.384
Sweet	6.75	5.37	6.36	6.35	6.80	0.357
Salty	6.84^{c}	8.69^{ab}	8.98^{a}	7.21^{bc}	7.53^{abc}	**0.035**
Bitter	5.03	4.08 b	4.96 ab	6.42 a	5.57 ab	0.136
Sour	2.39	2.42	2.58	2.61	2.25	0.946
Umami	5.58	4.76	5.05	4.23	4.81	0.279
Grainy	21.56^{bc}	18.82^{c}	23.92^{ab}	27.64^{a}	23.90^{ab}	**< 0.001**
Firm	18.99^{b}	18.73^{b}	25.98^{a}	29.65^{a}	21.08^{b}	**< 0.001**
Amassment	10.21^{c}	11.50^{bc}	14.04^{ab}	16.30^{a}	13.36^{ab}	**0.001**
Adhesive	15.31^{b}	16.65^{b}	22.92^{a}	21.62^{a}	19.37^{ab}	**0.001**
Homogeneous	12.65	14.12	13.06	11.61	11.82	0.446
Elastic	8.09^{a}	7.56^{ab}	6.07^{bc}	5.46^{c}	7.22^{abc}	**0.032**
Chewy	16.61^{b}	19.13^{b}	23.25^{a}	24.76^{a}	19.18^{b}	**< 0.001**

between instrumental colour data and sensory perception is not unusual, since human colour perception is influenced not only by colour itself but also by surface appearance, gloss, translucency and structural irregularities (Hutchings, 2002). These factors could make pasta sample appeared visually darker even when lightness increases. Therefore, this may explain why consumers described T50 sample as browner, together with its higher perception of raw cereal flavour, in line with previous evidence that colour can influence flavour perception (Spence et al., 2010). Among the taste-related sensory attributes, only saltiness differed significantly among the samples ($p < 0.05$). In particular, both Mozzarella *scotta*-based pasta samples were perceived as significantly saltier than Ctrl, while no significant differences were found between Mozzarella and Toma *scotta*-based samples. This result suggested that the type of *scotta* did not affect saltiness perception. Moreover, the increased saltiness compared to the control sample may be partially attributed to the peptide content in *scotta*. Indeed, Pontonio et al. (2021) demonstrated that microbial fermentation of *scotta* produced peptides with anti-ACE activity that also enhanced the sapidity in fortified ricotta products. These findings suggested that the use of *scotta* can contribute not only in providing bioactive compounds with health properties, but also it can help deliver peptides and fat responsible for flavour and sapidity (Bergamaschi & Bittante, 2018), thus influencing the overall sensory profile of products to which it is added.

Although no statistically significant differences were observed in the instrumental texture parameters of the cooked pasta samples, sensory analysis results showed significant differences in sensory texture-related attributes across samples ($p < 0.05$). This discrepancy may be explained by the fact that the instrumental texture measurements, which often provide objective and reproducible data on pasta texture, may not fully capture the complex and multidimensional nature of the food texture perception. Indeed, human texture perception during mastication involves multiple factors, including individual differences in oral tactile acuity and oral processing behaviour (Liu et al., 2022). In this study, sensory textural attributes were strongly influenced by both the type and concentrations of *scotta* used. T50 showed significantly higher intensities for grainy, firm, amassment and chewy attributes, alongside a lower score for the elastic attribute, resulting in a less balanced and less pleasant texture. Therefore, when reformulating pasta using dairy by-products like *scotta*, it is pivotal to consider not only the nutritional and environmental benefits but also their potential impact on texture perception, which is critical for consumers' acceptability.

Consumers' opinion about the appropriateness of using *scotta* as a water substitute in pasta production obtained a mean score of 4.8 on a seven-point scale, indicating that participants perceived this upcycling approach as slightly appropriate. Nevertheless, the willingness to buy *scotta*-based pasta obtained an average score of 5.1 on a seven-point scale, suggesting a slight positive interest towards this innovative product. Similar evidence was reported for other cereal-based products reformulated with dairy by-products. Indeed, Ricci et al. (2026) showed that the inclusion of upcycled second cheese whey in sourdough bread improved key sensory attributes, mainly related to texture and appearance, leading to higher consumers' overall liking. From a circular economy perspective, these results are particularly relevant since consumers' interest represents a critical enabling factor for the successful reintegration of food by-products into the food supply chain for human consumption (Aschemann-Witzel and Stangherlin, 2021). These findings align with previous research showing that consumers were more likely to purchase products made with by-products when they perceive them safe and nutritious and when they consider this practice appropriate to increase the sustainability of the food supply chain, thus consistent with consumers' ethical and environmental values (Hellali & Koraï, 2023; Tian et al., 2022). In this context, the reuse of *scotta* not only contributes to waste reduction but also supports resource efficiency by partially or totally replacing water, strengthening its relevance within the circular economy framework. Indeed, previous research demonstrated that attitudes towards and purchase intentions of upcycled foods tend to increase when consumers are informed about the environmental and health benefits of the upcycling approach (Cela et al., 2024; Coderoni & Perito, 2020). Conversely, other studies have demonstrated that consumers' scepticism, particularly concerns about the potential impacts of upcycled ingredients on sensory quality, safety and naturalness of food products, can negatively affect their willingness to buy (Hellali et al., 2023; Melios et al., 2025). This suggested the importance of demonstrating that circular economy solutions can be implemented without compromising the overall quality, as observed for the *scotta*-based formulations of the present study. Therefore, these results support the growing body of literature that emphasizes the important role of consumers' perception in a successful commercialization of sustainable food products, suggesting to the producers that informing consumers about the sustainability aspects or promoting the importance of reusing a by-product, as *scotta* in the context of this study, could facilitate consumers' acceptability and improve marketability of food products from circular economy approaches.

3.4. Multivariate associations among sensory and physicochemical characteristics of scotta-based pasta samples

The first two dimensions of the MFA (F1 and F2) explained 75.46 % of the total variance, with F1 accounting for 48.8 % and F2 for 26.7 %. As shown in the loading plot (Fig. 1A), F1 was positively correlated with sensory attributes (except for the elastic attribute), proximate composition, lightness of cooked pasta and TPC. Conversely, liking scores, cooking quality parameters, and RSA were negatively correlated along F1. This result suggested that pasta samples with higher consumers' acceptability were those that also exhibited longer cooking time and higher water absorption, but also enhanced health properties. However, TPC was not positively correlated with RSA, implying that the antioxidant activity was not primarily due to polyphenols, but could be attributable to other bioactive compounds, such as peptides derived from *scotta*. Indeed, RSA was mainly associated with Mozzarella *scotta*-based pasta samples, likely reflecting the bioactive potential of residual whey proteins, such as lactoferrin, retained during the production of Mozzarella cheese (Gernigon et al., 2010). Moreover, RSA was also strongly correlated with saltiness perception. These results were in line with findings by Blaschek et al. (2007) and supported the hypothesis that sweet whey (derived from Mozzarella cheese production) contains

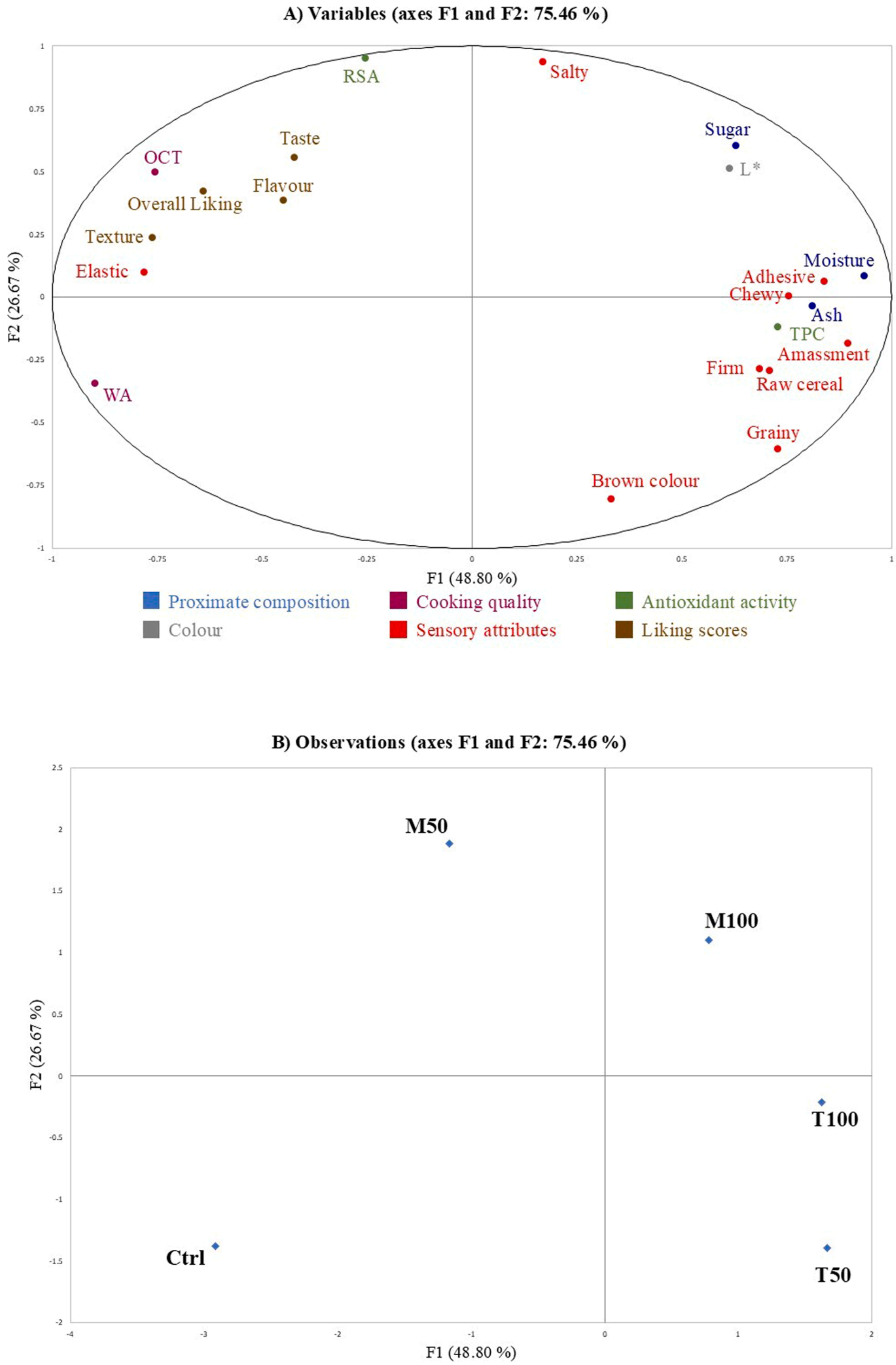

Figure 1. Loading plot (liking scores were added as supplementary variables) (A) and score plot (B) of Multiple Factor Analysis of physicochemical parameters and sensory attributes of pasta samples.

peptides with antioxidant and taste-enhancing properties.

As shown in the MFA score plot (Fig. 1B), F2 allowed to classify samples according to *scotta* type. Mozzarella *scotta*-based pasta samples were located in the upper quadrants, associated with liking scores and RSA, indicating that the use of Mozzarella *scotta* yielded pasta samples (especially M50) with acceptable sensory and functional properties. On the other hand, Toma *scotta*-based pasta samples were grouped in the lower-right quadrant, characterized by higher intensities of chewiness, amassment, firmness, grainy texture and brown colour, attributes negatively correlated with liking scores, thus suggesting that these samples were less appealing for the participants due to an unbalanced sensory profile. Furthermore, the control sample was positioned distinctly apart from all *scotta*-based samples, confirming the strong impact of the *scotta* use on the pasta overall profile.

Among the evaluated variables, sensory attributes emerged as the primary driver of liking, with a high RV coefficient of 0.812, followed by cooking quality parameters (RV coefficient: 0.377), although the latter showed a more moderate influence. This finding highlighted the critical role of sensory perception, particularly texture and visual appearance, in shaping consumers' acceptability. These results align with those from previous studies reporting that textural attributes of pasta - such roughness and the cooking performance - are critical in determining the consumers' satisfaction (Di Monaco et al., 2004; Jhans et al., 2025).

3.5. Limitations and outlook

Only two types of *scotta* (from Mozzarella and Toma cheese production) were tested in this study. Since the chemical composition of *scotta* may vary depending on cheese type, milk origin and processing conditions, future studies should consider *scotta* obtained from other cheese-making processes to broaden the applicability of the findings.

Another limitation of this study concerns the replication of pasta formulations. Each formulation was produced as single pilot-scale batch rather than through multiple independent production trials. Although this approach reflects industrial conditions and variability was addressed through the use of three process-based sub-batches as replicates, further studies involving repeated independent productions would strengthen the robustness of formulation-level conclusions. Moreover, further research is needed to evaluate the scalability of *scotta* use in pasta production at an industrial level and to assess its feasibility as a water substitute in other staple foods, such as bread and noodles.

In addition, the participants involved in the sensory analysis consisted mainly of young adults. Since age-related differences in oral masticatory behaviour and oral processing may influence the texture perception (Mioche et al., 2004), the sensory results may not represent older consumers' groups. Future studies should therefore include a wider age range to improve the generalizability of the sensory findings.

4. Conclusions

This study demonstrated that *scotta*, a dairy by-product, could successfully replace water in pasta production. *Scotta* influenced technological properties, such as cooking time and water absorption, and also enhanced the functional qualities of the cooked pasta in terms of RSA and TPC. *Scotta* substitution mainly influenced the texture-related sensory attributes (but not the instrumental texture parameters) and the saltiness perception of the final pasta samples. Multivariate analysis demonstrated that *scotta* type played a critical role in shaping the final product characteristics, with M50 sample emerging as the most promising formulation, offering a balanced sensory profile, enhanced antioxidant activity and high consumers' acceptability. Conversely, 100 % Toma *scotta* negatively affected pasta texture, leading to firmer and more adhesive textures, thus reducing liking. From an industrial perspective, Mozzarella *scotta* may be ideal for applications requiring softer, more elastic textures, while Toma *scotta* could be advantageous for products needing firmer textures.

Beyond its technological and sensory implications, this study supported the application of circular economy principles into food processing by demonstrating how a dairy by-product can be effectively upcycled into a staple food. Overall, this study suggested *scotta* as a sustainable ingredient that reduces dairy waste and promote innovation in pasta production, aligning with several Sustainable Development Goals (SDGs), specifically: SDG 2 (Zero Hunger), by promoting the development of nutrient-rich foods; SDG 6 (Clean Water and Sanitization), by reducing the industrial water use; SDG 12 (Responsible Consumption and Production), by promoting by-products upcycling.

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Ethical statement

The study was conducted in accordance with the ethical guidelines of the Declaration of Helsinki and received approval from the Ethics Committee of the University of Gastronomic Sciences in Pollenzo (Ethics Committee Proceedings n. 05.2024). Informed consent was obtained by participants prior sensory evaluation.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT (free version) in order to revise the English of some sentences so as to improve the readability of the manuscript. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

CRediT authorship contribution statement

Nazarena Cela: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Marta Bertolino:** Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Anna Olivero:** Investigation. **Ascanio Alberto D'Aloia:** Investigation. **Erika Bertone:** Investigation. **Chiara Nervo:** Visualization, Resources, Investigation. **Michele Ricci:** Validation, Methodology, Formal analysis. **Daniela Ghirardello:** Methodology, Formal analysis. **Giuseppe Zeppa:** Writing – review & editing, Resources, Formal analysis. **Luisa Torri:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, 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.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.afres.2026.101755.

Data availability

Data will be made available on request.

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