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Evolution of the Italian *pasta ripiena*: the first steps toward a scientific classification

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Abstract
In this study, phylogenetic and biogeographic methods are used to investigate the evolutionary relationships between various types of Italian *pasta ripiena* (filled pasta) and related representatives from across Eurasia, using information from their geography, shape, content and cooking methods. Our results showed that, with the exception of the Sardinian *Culurgiones*, all the other *pasta ripiena* from Italy likely had a single origin in the northern parts of the country. Based on the proposed evolutionary hypothesis, the Italian pasta are divided into two main clades: a *ravioli* clade mainly characterized by a more or less flat shape, and a *tortellini* clade mainly characterized by a three-dimensional shape. The implications of these findings are further discussed.

Keywords Mediterranean cuisine · Eurasian food · Dumplings · Phylogenetic methods

1 Introduction

Across Italy, a dizzying array of local variants of stuffed-pasta (*pasta ripiena*) dishes are prepared and served that often, from one town to another, show minor differences in size, shape, ingredients, or methods of preparation and serving. They are known by many different names, but the common feature in all *pasta ripiena* is the placement of uncooked filling in a thin shell made of rolled-out dough, which is then closed and shaped into specific forms before cooking. The use of local wild food plants or varieties of vegetables, herbs and spices as ingredients for filling or serving sauces adds unique layers of authenticity to family recipes that are often passed down for generations, reflecting the unique biocultural diversity in the country [1].

The Italian *pasta ripiena* are part of a large family of Eurasian stuffed dumplings that similarly come in a wide array of shapes and forms and are known by many different names, for example, the Turkish *manti*, German *maultaschen*, Polish *pierogi*, Jewish *kreplach*, Russian *pelmeni*, Georgian *khinkali,* Tibetan *momo*, Chinese *wonton*, Japanese *gyoza*, and many others. It is unclear whether all dumplings had a singular origin or evolved independently, or how the remarkable diversity observed in Italy is related to the greater variation present in Eurasia. Based on linguistic similarities, it has been

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speculated that stuffed dumplings were probably first invented in the Middle East and subsequently spread across Eurasia by Turkic and Iranian peoples [2]. Dumplings were known in China during the Han Empire (206 BC-220 AD) [3], where archaeological remnants of noodles from this period were also discovered [4]; however, in the same era, pasta had not yet made its appearance in Europe. The Italian *ravioli* have also been suggested to be a descendent of the Greek *manti* [5]. However, such scholarly theories often lack solid empirical evidence.

In Italy, *ravioli* are probably the oldest historically documented filled pasta, even though the early iterations of this dish evidently did not include the enclosing pasta casing [6]. Between the 12 and 13 centuries, a settler from Savona agreed to provide his master with a lunch for three people made of bread, wine, meat and *ravioli,* during the grape harvest [7]. *Tortelli* [8] and *agnolotti* [9] first appeared in literature much later. However, the origins of the iconic *tortellini* are controversial. The long-standing historical feud between the cities of Bologna and Modena over who invented the *tortellini* was symbolically settled at the end of the 19 century by Bolognese poet and satirist Giuseppe Ceri, who, in his poem "*L'ombelico di Venere*" (the navel of Venus), declared Castelfranco Emilia, a town halfway between the two cities, to be the birthplace of *tortellini*. According to this legend, one day, while Venus, Mars and Bacchus were visiting a tavern in Castelfranco Emilia, the innkeeper inadvertently caught Venus in a state of undress and was so astonished at the sight of the goddess' navel that he ran into the kitchen and created tortellini in her honor. Clearly, a product as perfect as tortellini could be inspired only by Venus, the goddess of beauty [10].

In his legendary 1891 cookbook, Pellegrino Artusi [11] listed a total of approximately 10 dishes that can be counted as *pasta ripiena,* including three different kinds of *tortellini*: Italian *tortellini* (*agnellotti*), *tortellini Bolognese*, and pigeon-meat *tortellini*. He included all the stuffed pasta under "*Minestre*" (soups) since they are usually served in broth.

The century following Artusi witnessed an explosion in nontraditional recipes for stuffed pasta across Italy, with entire cookbooks dedicated to hundreds of new and unique varieties. David Alexander's [12] modern morphological classification of Italian pasta includes the "*ravioli* (filled pasta) family", with 33 dishes grouped into four different types: "Sachet", Circular, Semi-circular, and "Crimped and tied" (Table 1). His map of regional origins correctly identified northern Italy as the hotspot of diversity for this group, with only two variants further south (*Crespelle* in Molise and '*Culigiones*' [sic] in Sardinia).

In this study, phylogenetic and cladistic approaches were employed for the first time to investigate the origin and evolution of *pasta ripiena,* with a focus on Italy. The investigation focused on whether it is possible to empirically categorize Italian stuffed pasta into discrete evolutionary units; If so, how did these groups appear and evolve, what are their unique characteristics (if any), and how are they related to one another and to non-Italian stuffed pasta.

2 Materials and methods

2.1 Selection of the in-group

Even though it is difficult to speak of "standard" or "main" varieties of *pasta ripiena*, for this study, a selection was made of 28 entries that represented not only the types that have moved out of local spread and into national/international spread (*ravioli, tortellini,* etc.) but also local specialties such as the Sardinian *culurgiones*, Mantovan *turtèl sguasaròt* and others, alongside nine selected outgroups from across Eurasia (Table 1). Some entries were considered despite their close nomenclatural affinity (e.g., *cjalzons* and *cjarsons*, both from Friuli Venezia Giulia), primarily to determine if there are any meaningful differences between them. All non-*ripiena* pasta, including *lasagna, gnocchi*, open-shelled, layered or rolled pasta, as well as deep-fried pastries such as *gnocco fritto*, *empanada* or *samosa,* were excluded from this study. Dessert varieties of some of these entries, where the filling is often sweet and very different, were also not considered.

2.2 Selection and coding of characters

Using recipes from Artusi's original 1891 edition of *La scienza in cucina e l'arte di mangiar bene* ("*Science in the kitchen and the art of eating well*") alongside popular cookbooks focused on pasta [6, 13–17] and additional online resources (giallozafferano.it, Pasta Grannies channel on YouTube.com), a dataset for the 37 entries with 15 characters was created, coding for a wide range of characteristics—from their geographical provenance to the ingredients used in making the pasta and the filling, as well as the cooking and serving methods (Table 2). Among the 15 characters, eight were binary (present or absent), and seven were multistate. The provenance of the Italian pasta was divided into four main regions: northern Italy (all of the north to Liguria and Emilia-Romagna), central Italy (Tuscany and Marche to Lazio and Abruzzo),

Table 1 Pasta entries and characters used in phylogenetic reconstruction

	Pasta/character	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Gyoza	0	4	0	0	1,2	1	2	0	1	0	1	1	2	1	1
2	Manti	0	4	0	1	0,1	1	2,3	1,5	0	0	1	0	2	2	0
3	Pierogi	0	4	0	1	1	0	0	0	1	1	0	0,1	2	2	0
4	Pelmeni	0	4	0	1	1	1	4	3,6	0	0	1	0	2	0	0
5	Maultaschen	0	4	0	1	3	0	0	1	1	1	1	0	3	2	0
6	Kreplach	0	4	0	0	2,3	0,1	0,3,4	0,1,2,3	1	0	1	0,1	3	0	0
7	Khinkali	0	4	0	0	2	1	8	5	1	0	1	0	0	0	0
8	Momo	0	4	0	0	1	1	8	0,5	1	0	1	3	0	0	0
9	Wonton	0	4	0	1	1,2	1	7,8	5,6	1	0	1	0	3	0	0
10	Agnolotti al plin	1	0	0	1	0	1	6	1	1	1	1	0	0	2	0
11	Anolini	1	0	0	1	0	0	1	3	0	1	1	0	3	0	0
12	Balanzoni	1	0	0	1	1,2	1	4	6	0	1	1	0	0	2	0
13	Cappellacci	1	0	0	1	1,2	1	4,5	6	0	0	1	0	1	1	0
14	Cappelletti	1	0	0	1	0,1	1	4	6	0	1	1	0	3	0	0
15	Caramelle	1	0	0	1	1	1	7	4	0	1	0	0,1	2	2	0
16	Casoncelli	1	0	0	1	1	1	0,7	4	1	1	1	0	2	2	1
17	Casunziei	1	0	0	1	1	0	0	0	1	0	0	0,1	0	2	1
18	Ciaronciè	1	0	0	1	1	0	0	0,1,2	1	0	0	0	0	2	1
19	Cjalzòns	1	0	0	1	1	0	0	0	1	1	0	0	2	2	1
20	Cjarsons	1	0	0	1	1	0,1	0	0,6	0	1	0	0	2	2	1
21	Culurgiones	1	3	1	0	1,2	1	2	5	1	0	0	0	2	0	0
22	Fagottini	1	0	0	1	0,1	1	3	5	0	1	0	0	0	2	0
23	Marubini	1	0	0	1	0,1	0,1	1,5	3,6	0	1	1	0	3	2	0
24	Minestra imbottita	1	0	0	1	0	0	1	1	0	1	0	0	3	0	0
25	Pansoti	1	0	0	1	1	1	4	6	1	1	0	0	2	2	0
26	Puligioni	1	3	1	1	1,2	0	1	1	0	1	0	0	2	0	0
27	Ravioli	1	0,1,2	0	1	1	0	0	1	0,1	0	0	0	2	2	0,1
28	Scarpinocc	1	0	0	1	1	1	7	4	0	1	0	0,1	2	2	0
29	Schlutzkrapfen	1	0	0	1	1	0	0	0	0	1	0	0	2	2	0
30	Tordelli	1	1	0	1	1	0	0	0	0	0	1	0	1	1	0
31	Tortel Dols	1	0	0	1	1,2	0	0	1	1	0	0	0	2	2	1
32	Tortelli	1	0,1	0	1	1	0,1	0,4	1,6	0	1	0	0	0	2	0,1
33	Tortelli alla lastra	1	1	0	0	3	0	1	1	1	1	0	2	0	0	0
34	Tortellini	1	0	0	1	0	1	5	6	0	1	1	0	3	0	0
35	Tortelloni	1	0	0	1	2	1	5	6	0	1	0	0	2	2	0
36	Turtèl sguasaròt	1	0	0	1	3	0	0	1	1	0	0	0,1	2	1	0
37	Zembi d'arzillo	1	0	0	1	1	0	1	1,3	1	0	1	0	1	1	0

southern Italy (Molise and Campania to Sicily), and Sardinia. Selected characteristics included whether the flour used in making the pasta was primarily soft or durum wheat, and whether the eggs were used in preparation of the dough. Pasta shapes were coded according to the scheme proposed by Schira [6], and pasta size was coded in four categories from small (e.g., *tortellini*) to very large (e.g., *tortelli alla lastra*). The flatness or three-dimensional nature of the filled pasta was also considered. The folding of the pasta was classified into nine categories, from simple folded-and-thumb-pressed to wrapped around the finger, rolled, or bundled. Other considerations included whether vegetables or meat constituted the main ingredient of the filling, and whether any dairy products were included. Cooking was coded as boiled, pan-fried, roasted or steamed pasta. It was also taken into account whether the final dish was served primarily in broth or with sauce, if the sauce was meat or nonmeat based, and whether butter or oil was used in serving.

Table 2 Characters used in the phylogenetic analysis

1	Provenance (0: foreign, 1: Italian)
2	Italian region (0: North, 1: Central, 2: South, 3: Sardinia)
3	Flour (0: soft wheat, 1: durum)
4	Pasta (0: no eggs, 1: eggs)
5	Pasta size (0: small, 1: medium, 2: large, 3: very large)
6	Flatness (0: more or less flat, 1: 3-dimensional)
7	Folding (0: folded over and edges pressed, 1: two separate layers, 2: oval bundle, 3: square bundle, 4: hat-shaped bundle, 5: hat-shaped with a hole, 6: folded upright, 7: rolled and press-shaped, 8: round bundle)
8	Shape (0: half-moon, 1: rectangular, 2: triangular, 3: round, 4: roll, 5: bundles, 6: hat shaped)
9	Filling: vegetables as the main ingredient (0: absent, 1: present)
10	Filling: dairy (0: absent, 1: present)
11	Filling: meat (0: absent, 1: present)
12	Cooking method (0: boiled, 1: fried, 2: roasted, 3: steamed)
13	Sauce (0: no sauce, 1: meat-based, 2: nonmeat-based, 3: served in broth)
14	Serving sauce (0: none, 1: oil-based, 2: butter-based)
15	Sweet filling (0: absent, 1: present)

2.3 Phylogenetic analysis

The final data matrix was converted into nexus format in MESQUITE [18]. A heuristic add-and-rearrange method was initially used with the tree search criterion set to treelength, using the Subtree Pruning and Regrafting (SPR) rearranger and a maximum number of equally good trees set to 10000. Bayesian analysis was conducted in MRBAYES 3.2.6 [19], with Markov Chain Monte Carlo (MCMC) analysis allowed to run for 50,000,000 generations and repeated multiple times to check for convergence and stationarity. The results were subsequently tested using TRACER 1.7.1 [20]. Trees were edited using FIGTREE 1.4.4 [21]. A Maximum likelihood (ML) tree was further generated with the IQTREE web server (http://iqtree.cibiv.univie.ac.at) [22] with 10000 ultrafast bootstrap replicates. Finally, the regional divisions selected for the provenance of Italian *pasta ripiena* were incorporated in an analysis to reconstruct the ancestral distributions. The R package BioGeoBEARS [23] was used to compare three possible models of past geographical range estimation based on the Akaike information criterion and, for each of them, also a variant with a founder effect (parameter j): dispersal–extinction–cladogenesis (DEC), dispersal–vicariance analysis (DIVALIKE) and BI for discrete areas (BAYAREALIKE). The program then reflects these likelihoods as pie charts with all possible ranges for each node and their respective probabilities. A maximum of four possible ancestral areas was allowed.

3 Results

3.1 Phylogenic analyses

Our inferred phylogenies using different methodologies demonstrated slightly different topologies (Fig. 1). As expected with variable categorical data, the overall support (bootstrap and Bayesian posterior probabilities) for deeper nodes was weak. Different types of pasta did not always group together based on their shape or provenance, and often appeared in unexpected sister-group relationships. Throughout our analyses, the Sardinian *culurgiones* had an unstable position, sometimes appearing within the Italian clade as a sister to the other Sardinian entry *puligioni* and sometimes among the outgroups. The Italian *pasta ripiena* was monophyletic only according to our Bayesian analysis. Entries with unique autapomorphies, such as *tortelli alla lastra* of Corezzo (a fire-baked pasta) or the *turtèl sguasaròt* of Mantova (bean-filled pasta served with peanut oil), appeared on long branches within clades with other pasta with whom they shared synapomorphies such as their shape or size.

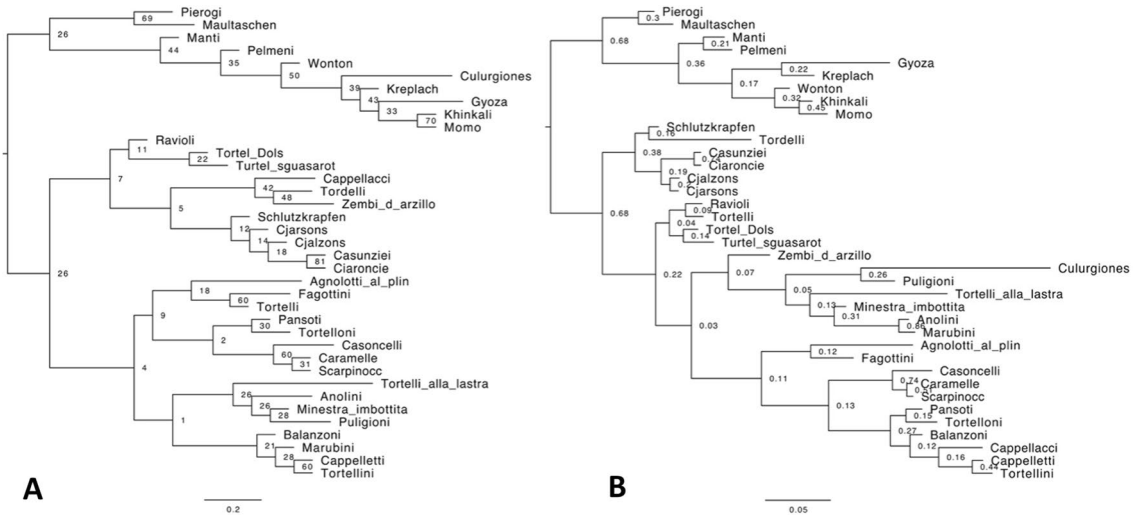

Fig. 1 Maximum Likelihood (**A**) and Bayesian (**B**) inference of the data. Values show (**A**) bootstrap support of 10000 replicates and (**B**) Bayesian Posterior Probabilities for each node

Throughout our analyses, aside from the outgroups, the Italian pasta appeared in two main groups: a "*ravioli* clade" and a "*tortellini* clade" (Fig. 2). The *ravioli clade* included *ravioli, tordelli, schlutzkrapfen, cjarsons, cjalzons, casunziei, ciaroncie, tortél-dóls,* and *turtel sguasaròt*. Even though, in our Maximum Likelihood analysis, this clade was monophyletic, it appeared paraphyletic in our Bayesian analysis (Fig. 1). Two additional entries (*cappellacci* and *zembi d'arzillo*) were also part of the *ravioli* group in our Maximum Likelihood analysis; however, they appeared as part of the *tortellini* clade in the Bayesian inference. The most important shared characteristic of this group (with the exception of *cappellacci*) is the "flatness" of their shape. On the other hand, the *tortellini* clade contained all the remaining Italian *pasta ripiena*, with the main shared characteristic being their three-dimensional nature. The rolled *pasta ripiena* entries *casoncelli, caramelle* and *scarpinocc* always clustered together.

3.2 Biogeographic analysis

The preferred biogeographical model according to the corrected Akaike information criterion was the dispersal–extinction–cladogenesis model with a founder effect (DEC + j) (Supplementary Information S1). This model predicted a high likelihood of a north-Italian origin for the ancestral Italian *pasta ripiena*. The Sardinian *culurgiones* was the only exception since it appeared among the outgroups, signaling a possible secondary origin.

4 Discussion

Contrary to Alexander [12] whose classification was based mainly on pasta shapes, our multivariate analyses showed that with the exception of *culurgiones,* all the other Italian filled pasta can be classified into two distinct groups: a "*ravioli* clade" and a "*tortellini* clade" (Fig. 2). In addition, it was revealed that these varieties had a single origin in northern Italy, with subsequent dispersal to other regions of the country. As indicated previously, most Italian filled pasta recipes are from the northern and central regions. This clustering is probably correlated with the climate specificities of different Italian regions and the associated differences in agricultural products and food sources available. For example, durum wheat – from which dry pasta shapes are produced – does not thrive on the Padania Plain; thus, fresh pasta, often produced with the addition of eggs, is the speciality of Emilia-Romagna [12]. In fact, the addition of eggs to dough is much more common in northern areas, with a few exceptions that also stand out in our phylogenetic analysis. A possible explanation for this high local diversity is the phenomenon of "variation on a common theme", where each town, region and state strived to have their own signature gastronomy and to claim a type of pasta for their own [12]. Our proposed evolutionary clustering shows that the now well-established distinctive pasta shapes were likely not so strongly differentiated in the past. A hypothetical framework that could explain this local radiation of shapes is a gradual differentiation in both space and time and the subsequent loss of intermediate forms in favor of more "identity-defining" shapes.

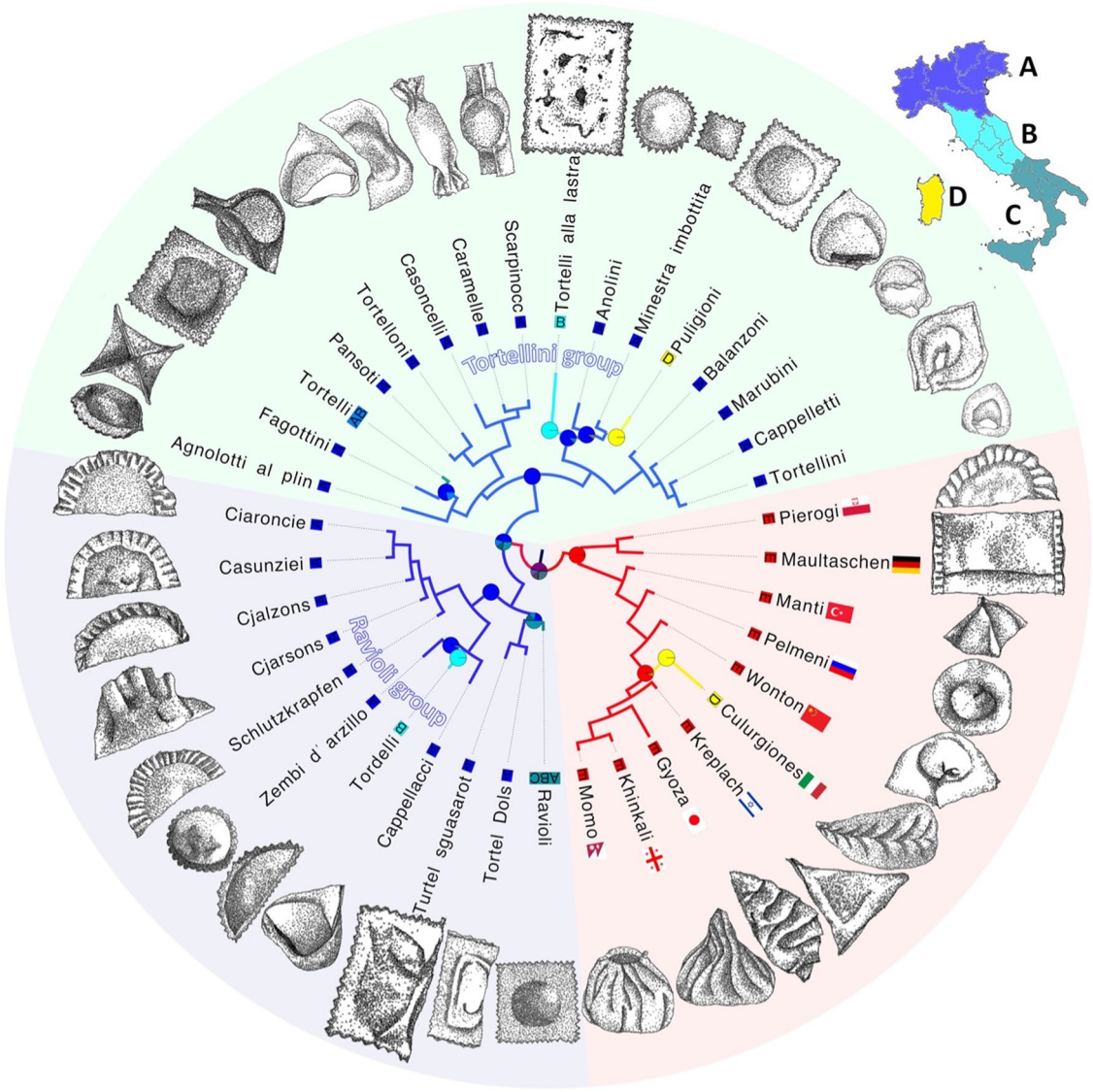

Fig. 2 Phylogeny of *pasta ripiena*. The geographical regions considered include **A**: northern Italy (blue), **B**: central Italy (aqua), **C**: southern Italy (green), **D**: Sardinia (yellow), and **E**: outgroups (red). Pie charts show ancestral distribution probabilities inferred by BioGeoBEARS

This "proximity" hypothesis, however, does not fully explain our results. Because of their unique characteristics, some of the Italian entries (e.g., *culurgiones* or *tortelli alla lastra*) often appeared among the outgroups, albeit with weak support. In fact, the latter two entries are the only Italian *pasta ripiena* prepared without eggs in the dough. *Culurgiones* in particular shares many other characteristics with Eurasian bundle-shaped dumplings and often appeared among the outgroups in our analyses, suggesting a second, independent origin with respect to the North Italian cluster. *Culurgiones* are made with durum wheat semolina and are endemic to the island of Sardinia, which is climatically, agriculturally, and historically different from northern and central parts of Italy.

One limitation of this study was that some crucial variables for which no data were available through primary sources (recipes) could not be codified, and thus they were excluded. An example pertains to the way filled pasta are consumed (e.g., the peculiar method of eating *khinkhali* with a characteristic imbibing of the juices). In addition, taste and other sensory properties could not be considered, i.e., the use of pork vs. cow meat, the exact nature of the seasoning (e.g., Allium-based vs. aromatic plants vs. others), the diverse amount of possible aged cheese varieties used (e.g., pecorino, parmigiano, etc.) or their rate of "umami" contributions. Sensory perception, an important indicator in food products, is largely influenced by shape [24, 25]. In the case of pasta, at the physicochemical level, shape affects the surface area exposed to boiling water, determining the rate of hydration and the degree of gelatinization of the starch during cooking,

thus affecting the textural properties and even the digestibility of the cooked pasta [26–29]. Texture, in turn, influences the oral tactile sensation and sensory perception [30]. Studies have shown that basic taste, such as sweetness, is related not only to the sugar content in a product but also to its hardness or viscosity, influencing the speed of its spread in the oral cavity during the eating process [31]. Furthermore, surface roughness or presence of hollow spaces, as also pertinent to pasta shapes, affects sauce adhesion and retention [32]. Each type of pasta is in fact an artificial geometric element on its own right. The mouth perceives the physical differences between one shape of pasta and another, providing the brain with different information about volume, texture, and smoothness. Hence, pasta with different shapes turn out differently with the same ingredients, and the multitude of existing shapes are by no means interchangeable for Italians because each has its "right" pairing with the sauce.

The shape and size of foods also affect consumer preference, as they can influence the implicit associations individuals make about an object and its value [33]. Shape has not only a pragmatic but also a symbolic and communicative function [34] and is easily recognizable and tied to cultural identity. A stiff dough of semolina or flour, water and possibly eggs is as malleable and versatile as clay and can be shaped as a distinctive and identifying element, historically established as "traditional," but without excluding the possibility of further evolution and innovation. 3D-printed unconventional pasta shapes, characterized by a high degree of personalization and complexity, have been developed [35] to convey cultural content [32], and the design concept of "morphing" [36], that is, a change in shape under certain conditions, has been recently applied to pasta [37]. Morphing pasta is flat, 2D pasta, that transforms into 3D during cooking due to water hydration and starch gelatinization. Morphing pasta is suitable for flat packaging, reducing shipping costs and storage space. Although not suitable for stuffed pasta, morphing technology is still another example of how many implications the shape of pasta has.

5 Conclusions

To the best of our knowledge, this is the first study to provide empirical evidence towards a scientific classification of Italian *pasta ripiena*. Even though the primary sources used to create the dataset for this study were by nature nonscientific, they are in many ways the most reliable sources due to their historicity and/or popular usage. The addition of other filled pasta and dumpling varieties from across Italy and Eurasia and the inclusion of other informative characters that can add further resolution to the phylogenetic inference are the next steps in this research. Evaluation of elements such as taste and methods of consumption would require surveys and experimental design and can perhaps be considered in a subsequent, more inclusive study on all Eurasian *pasta ripiena*.

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Author contributions V.N. created the dataset, performed the phylogenetic analyses and wrote the manuscript. A.Pa. revised the manuscript and wrote part of the discussion. A.Pi. provided intellectual input and revised the manuscript. V.T. performed biogeographic analysis. S.B. and T.P. provided analytical perspective, wrote part of the discussion and revised the manuscript. All authors have read, reviewed, and agreed to the published version of the manuscript.

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Data availability All the data used in this study are provided in their entirety within the paper or as supplementary materials.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication All the authors have approved the manuscript for submission.

Competing interests The authors have no relevant financial or nonfinancial interests to disclose.

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