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Special Section: Pizza and Popcorn Research

Improbable Research Reviews*

News & Notes

ANNALS OF IMPROBABLE RESEARCH

On the Front Cover
Researchers have gained surprising insights from pizza, and from popcorn.

On the Back Cover
Cookies named, apparently, after the inventors of calculus—offered for sale in a supermarket in Somerville, Massachusetts. Photo: Alice Shirrell Kaswell.

Some Coming Events

See IMPROBABLE.COM for details of these and other events:

January 2018
Arisia, Boston, MA, USA
Princeton U, USA

February 2018
SLAS Conference, San Diego, CA, USA
Salk Institute, La Jolla, CA, USA
AAAS Annual Mtg, Austin, TX, USA
Atlanta, GA, USA

March–April 2018
Ig Nobel EuroTour

April 2018
Portland, Oregon, USA

July 2018
Ig Nobel Ceremony Tickets go on sale

September 13, 2018
Ig Nobel Prize Ceremony, Harvard U

Autumn 2018
Japan
Ig Nobel Fall EuroTour

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The Evolution of Pizza

Novel insights into the fourth domain of life

by Russ Hodge,[1] Pablo Mier Munoz,[2] and Miguel Andrade-Navarro[2]

This study attempts to deliver pizza into a proper—and more widely appreciated—place in the field of biology.

The Unwonted Absence of Pizza in Biology

Pizza has long held a stigma in biological research. Linneaus, who was intimately familiar with pizza's properties as an aphrodisiac, failed to recognize and study it as a living organism. As a result, species of pizza found no place within Linneaus's elaborate system to classify all species of life.

In modern times, pizza is entirely omitted from the clade systems of evolutionary biologists. Add to this the nigh impossibility of maintaining pizza, for anything more than short durations, in laboratories. In laboratory cultures, pizza tends to spontaneously disappear, through mechanisms that are poorly understood.

The biological study of pizza is complicated by the fact that from one point of view a pizza resembles a single cell, with a crusty membrane and a diversity of clearly defined organelles, while from another perspective it shares properties of highly developed multicellular organisms, and from a third it seems to resemble an ecosphere containing a diverse range of symbiotic subspecies.

An additional characteristic of pizza—that pizzas never evolved a skeletal or exoskeletal system—explains the virtual absence of fossil remains. The paucity of fossils in turn explains why there has been little interest from the paleobiology community, which might otherwise have provided insights into the descent of modern pizza species.

An Evolutionary Tree of Pizza

The synthesis of Darwin's theory of evolution with findings from genetics has led to modern, computational approaches that compare the features of modern organisms so as to reconstruct the characteristics of ancestral species. Here we apply the basic principle of "common descent" to construct the first evolutionary tree of pizza.

Modern pizza varieties have clearly undergone human domestication and selection, and a small number of mutant strains have spontaneously appeared in recent years. While these factors confound the picture to some degree, bioinformatic analysis resolves central questions about pizza biology that have long resisted explanation.

Archaea, Bacteria, Eukarya, Pizza

The resulting diagram captures the path by which current species of pizza arose from a single common ancestor, branching off into major subgroups and finally achieving modern forms. This provides insights into fundamental biological processes that are unique, supporting the claim that pizza represents a fourth domain of life that is distinct from archaea, bacteria, and eukarya but has interacted with them in ways that have shaped its (and their) evolution.

We find evidence that pizza has managed to co-opt fundamental biological processes from the other domains of life and combine them in a way that hints at hitherto unexplored evolutionary mechanisms. Pizza appears to have snatched genes from various sources on its way to becoming an independent organism, then undergone a phase in which it became wholly dependent on human domestication, leading to a

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simplification of its biology. Our study suggests that the appearance of pizza in complex ecospheres containing other life forms influences them on several levels—from the neurological to the behavioral to the social, altering patterns of predation and other types of interspecies interactions.

Methods and Results

We visited approximately 100 different Italian restaurants in a sample of no less than five European countries over a period of 4 years (extrapolated from social media statistics of the authors: FourSquare, Google Location History, etc.) to gather the names and ingredients present in a total of 58 different pizzas (Supp.File1). While we did not taste them all, we can attest that none are venomous, and that their organoleptic qualities can therefore be successfully transmitted mouth-to-mouth to the next generation of diners.

The ingredients were clustered in 9 groups according to their origins and use in cuisine (Table 1).

Tomato sauce and mozzarella form their own groups, as these are not considered ingredients but rather inherent components of the pizza (Combet *et al*., 2014).

The pineapple was set apart in a group by itself as an obvious aberration, due to the fact that it is universally recognized as a dysfunctional mutation that arises from a hybridization event (somewhat like the mule) and cannot produce viable offspring.

Table 1. Ingredients considered per group.

Class	Ingredients
Tomato sauce	Tomato sauce
Mozzarella	Mozzarella
Extra sauce	Cream, truffle cream
Extra cheese	Gorgonzola, parmesan, ricotta cheese, fontina cheese, scamorza, stracchino, asiago
Meat / eggs	Beef, salami, raw ham, ham, bacon, sausage, bresaola, egg
Fish / seafood	Tuna, anchovies, seafood
Pineapple	Pineapple
Condiments / herbs	Pepper/green peppers, oregano, rosemary, parsley, Genoese pesto, garlic, olive oil
Vegetables	Artichoke, zucchini, asparagus, spinach, peas, eggplant, assorted vegetables, sliced tomato, courgette flower, onions, olives, mushrooms, rucola/rocket, potato, french fries, corn, polenta, radicchio

It is notable that not a single pizza contains more than three ingredients from the same group, which hints that they cause some sort of synthetic lethality, or have effects resembling the acquisition of excess chromosomes.

The pizzas were scored by counting the number of ingredients they contained per group. Exceptions are the tomato sauce and mozzarella, which were each weighted as three (rather than one) ingredients, due to their importance in the general composition of pizza. The data was analyzed using the R programming language and Rstudio, clustering the pizzas based on their ingredients. The result was plotted in a clustered heatmap using the *pheatmap* R package (Kolde, 2015).

Tomato sauce and mozzarella are the key components in the pizza and serve as classifiers (Figure 1). Ingredients from the meat/eggs and/or vegetables groups are often used as the toppings to go together with the main components of the pizzas.

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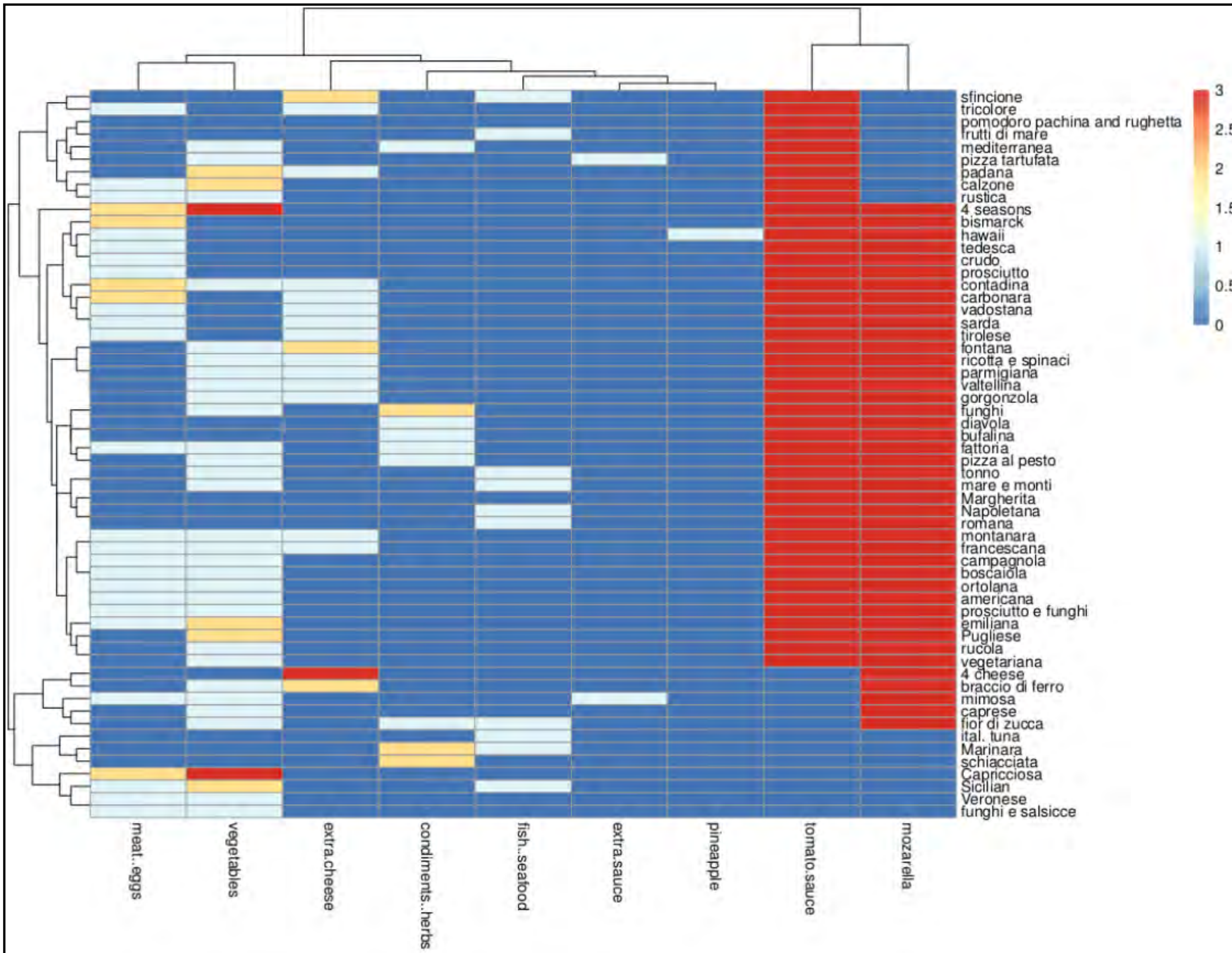

Figure 1. *Clustering of the 58 types of pizzas analyzed based on their ingredient composition.*

Discussion

This is the first rigorous investigation of the origins and evolution of pizza, a form of life that has been shamefully neglected by science even as it has been shamelessly devoured by scientists. While the reasons are unclear, one cannot rule out some sort of large-scale conspiracy on the part of commercial entities. It would not be in their interest to recognize pizza as a life form; such recognition would likely trigger a cascade of intrusive regulatory measures that would curtail society's wholly utilitarian approach to pizza's handling and use. Ethical issues, too, have had an influence: in many societies, pizza is treated as an inanimate object, with no consideration for the possibility that pizza might possess some sort of limited awareness and thus could experience feelings of distress or pain.

In modern times, pizza species have become entirely dependent on human cultivation, just like many plants, domesticated animals, and model organisms that are studied in laboratories. The biology of pizzas has become simplified through this dependency.

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Modern forms have, almost certainly, lost genes that were originally crucial to their ancestors' survival. As a result, pizzas are no longer competent for survival in the wild. Thus, their evolutionary path likely resembles that of pathogens and viruses.

Under normal processes of natural selection, organisms that are tastiest to their predators are eaten more, and are subject to intense negative evolutionary selection. This would also be the case for pizza, particularly since it has no intrinsic means of locomotion that would allow it to escape from its human predators. But domestication has reversed this trend, positively selecting for the forms that are most likely to be eaten.

Nutritional and Health Implications for Non-Pizza Species

Pizza is a fixture of worldwide ecosystems and global food chains, nourishing species as diverse as college students, police, bowling teams, and other categories of humans—and also dogs, cats, hamsters, pigs, rats, cockroaches, crocodiles, fish, etc. The decaying remains of pizza crusts that have fallen down cracks in sofas provide a rich environment for microbial life, including bacteria such as legionella, Yersinia pestis and *Mycobacterium leprae,* which might otherwise be in danger of extinction. In this way, pizza plays a central role in global biodiversity; one might even regard it as the glue that holds everything together. But this notion is somewhat speculative.

Technical obstacles have made it difficult to maintain pizza in laboratory cultures, creating a sort of black hole of knowledge with regards to its biology. This is alarming in light of the numerous epidemiological studies tying pizza to serious health problems including obesity, addiction, attention deficit disorders, frostbite, burnt tongues, and deaths related to placing aluminum foil in microwave ovens.

Excessive consumption retards human cognitive development, pushing adolescence far into the college years, a situation which can only be reversed by adding vegetables to the diet. Predatory consumption of pizza has led to a major reduction of human motility; delivery services have completely eliminated the hunter-gatherer activity that used to be required to obtain it.

Summary of Pizza's Biological Features

By applying well-established methods of phylogenetic analysis to the features of pizza (namely, the ingredients found in 58 extant species) we derived the first systematic evolutionary account of its descent from an ancestral form. The results point firmly to a last common ancestor, providing insights into fundamental aspects of its biochemistry, development, and the selective forces that have shaped its evolution into diverse types. Our observations of pizza *in situ* suggest that its basic biology draws on unique features which are hard to reconcile with those of traditional biological models. A key finding is that the ancestral pizza exhibited very little elaboration of specialized structures. It consisted of only three tissues: dough, tomato sauce, and mozzarella. Each of these tissues exhibits a high degree of molecular complexity while having stable biophysical properties that are crucial to maintaining the integrity of the organism over time.

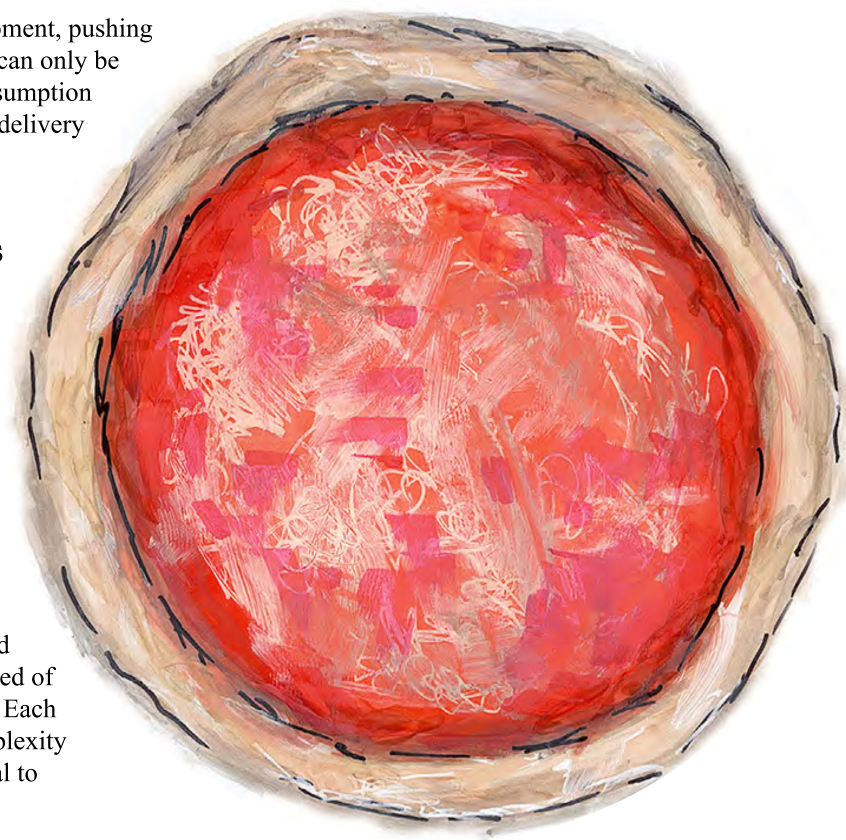

Figure 2. *Artist's reconstruction of the last common ancestor of all current species of pizza.*

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1. The Pizza Lifecycle

The pizza lifecycle is marked by the three phases embryogenesis, maturation, and decline.

Entry into a phase is determined by environmental factors: embryogenesis takes place at room temperature; maturation begins when the temperature dramatically rises to about 220 degrees Celsius and usually lasts 10-12 minutes. Returning to normal room temperature introduces a brief period of homeostasis after which pizza enters the phase of decline.

Laboratory experiments have shown that pizzas which have completed embryogenesis can be preserved through cryopreservation, which induces a state of dormancy or hibernation. They can be maintained this way for a year or two without any apparent damage. The decline phase can be prolonged by a day or two through cooling, after which a brief exposure to heat is used to revive the pizza. This may cause it to repeat the last stages of maturation and then enter the decline phase, which is now accelerated.

At the beginning of the decline phase, most pizzas separate into segments. Division begins at the center, with cracks that spread radially to produce wedge-shaped units—most often an even number (between 4 and 12) of segments. It is unclear whether this process begins at the middle and radiates outwards, or starts at an edge, traverses the middle, and arrives at the other side. The mechanisms required for these two processes would be fundamentally different. Either way, a number of fascinating questions arise: As each split begins, what molecular signal does it follow to stay on course rather than veer away? What determines the total number of divisions that will occur? How does one side of the pizza "know" what is happening on the other side, so that the proportions of the slices remain equal? We are exploring these questions through the "Virtual Pizza," which we developed for use in computer simulations.

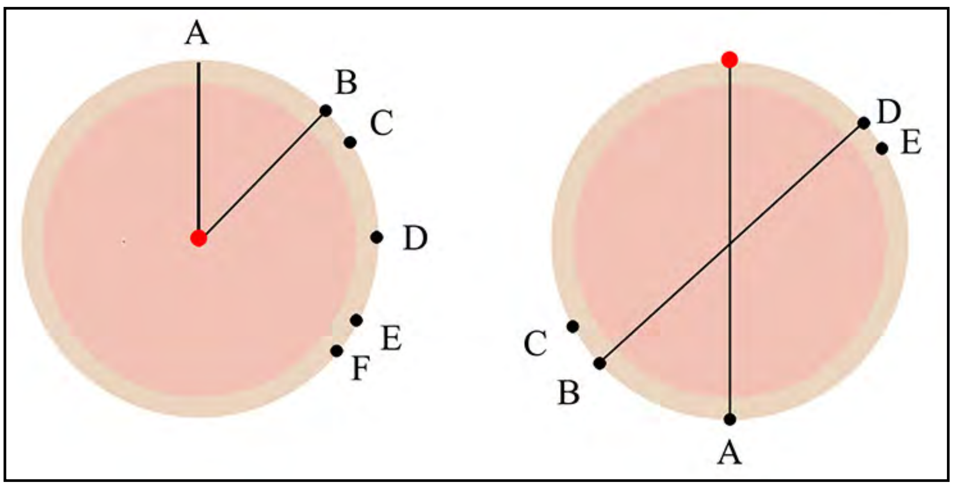

Figure 3. *The Virtual Pizza: Computer modeling of alternative slicing.*

Left: Model assuming that slicing begins at the center (red dot). The first slice is directed toward either A. The second toward either B (if 6 slices will be made) or C (for 4), likely through the detection of a signal gradient that keeps it on course. That decision determines all that follows: If B has been selected for the second slice, C is skipped and the third slice aims at D. If C has been selected instead, then D must be skipped. It is unclear whether skipping is regulated by mechanisms at the center, or through some sort of communication between B and C (e.g., a positive signal at B inhibits the signal at C, etc.)

Right: Model assuming that slicing begins at the border and traverses the pizza. In this case the first slice must aim for A, crossing the middle, again through some sort of guidance system, or events at the initiating border. Once the slice has been completed, a decision-making mechanism directs the onset of the next slice to either B or C. At that point the second slice must be informed to target D or E.

The biological functions of the divisions are unclear. We hypothesize that they provide an evolutionary advantage through an unusual route: a failure to divide causes predators to fight over the whole. Only a very small fraction of these conflicts are likely to be fatal, but over long periods of time this offers a slight advantage to animals that feed off the sliced form. Since pizza now exists only as a domesticated species, there is perforce a direct correlation of its genome with those of the predators. So generally, variants of pizza that promote harmonious behavior in humans and other predators are more likely to survive.

Ultimately, its integration into the human diet may have stimulated the development of modes of primitive social organization that became more and more elaborate until they acquired the forms familiar to us today: priesthoods, the military, and governments.

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2. Tissue Structure Through the Lifecycle

Dough begins as an elastic substance under room temperature, which is characteristic of the environment of embryogenesis; in the heating phase it becomes crisp, and remains that way as it cools, matures, and approaches death.

The sauce begins as a thick fluid which crystallizes somewhat at the pinnacle of the heating phase, remaining gummy through the first phases of cooling, then hardens until it is nearly all crystallized at the end of cooling.

Mozzarella begins as a rubbery substance, melts into a liquid under heat, and only hardens after an extended period of cooling over time.

These transformations of the three tissues do not alter the basic structural integrity of the whole, unless the pizza is subjected to unusual biomechanical forces such as it would encounter when flung through the air. An embryonic pizza would stretch and fly apart; the hardness of a mature pizza gives it the properties of a Frisbee.

Figure 4. *Layers of pizza tissue structure. Tissue layers of pizza at the completion of embryogenesis, traverse section. Once the primary layer (dough) has spread across a surface, it induces formation of the secondary layer, which then induces the tertiary. Without the protection of a membrane or additional layer of dough, the top two layers are continually exposed to extreme changes of environmental conditions that has surely restricted the evolutionary potential of pizza species.*

3. Embryogenesis

The earliest stage of pizza's embryonic development bears some similarities to *Dictyostelium* ("slime mold"), an organism that lies at the borderline between unicellular and multicellular life.

Dough assembles in an environment containing sufficient concentrations of the necessary chemical and biological ingredients: particles of wheat, water, sugar, and some form of oil. Such environments usually contain abundant populations of yeast cells, which get dragged along as the components are attracted to a central location, probably by sensing chemokine-like molecules that have been secreted by a cook's hands.

Upon arrival, the components merge in a sort of symbiotic collective that draws on the genes of the wheat and yeast to trigger a series of metabolic reactions that derive energy from the sugar and oil. The result is to fuse everything into a pliant, undifferentiated mass of dough. Originally this is a ball-shaped mass with stem-cell like properties that may yield a single pizza, or be pinched off to form genetically identical twins.

The ball spreads across a surface to form a flat, circular basal membrane on which new layers will arise. The dough induces the formation of tomato sauce, rapidly followed by a layer of mozzarella. In more elaborate forms, additional organelles such as salami or anchovies arise through chemical interactions between the sauce and mozzarella. Yet the three-layered structure is retained.

This is highly reminiscent of the tissues that arise in animal gastrulation, but that process begins with a group of cells that have retained the ball-like shape, causing inner layers to interact in more complex ways. This difference is a determining factor in pizza evolution, because it leaves the lower layer attached to a substrate, while the upper remains naked and exposed to the environment. The lack of a membrane or shell means that the upper layers of a pizza must constantly contend with fluctuations in the surrounding environment.

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This single difference, combined with the fact that embryonic pizza does not have a womb to protect it from dramatic changes in temperature, probably severely restricted the degree to which ancient pizzas could vary from the original design. While eventually pizzas developed specialized organelles such as salami and funghi, there was never much variation to serve as the basis for selection. So the type of evolutionary tinkering that occurred in animals and shaped the formation of highly sophisticated organs such as the brain never occurred in pizza.

Conclusions

Our investigation provides the first account of the evolutionary route by which modern species of pizza diverged from an ancient, ancestral form. We characterize the last common ancestor as sharing the three-layer structure of modern pizzas, which resembles the first stage of animal gastrulation. In contrast to animals, however, pizza got stuck there, and never added additional developmental stages.

It is interesting to speculate what might have happened if instead of flattening, dough had retained its original, ball-shaped form, and built layers of sauce and cheese inside. *Pizza calzone*, a modern species, obtains this type of structure by folding the membranous dough around to seal off the interior, but this is the very last stage in its embryonic development. If, in the distant past, this progression had advanced to the beginning of embryogenesis, pizzas might have followed an evolutionary path much more like our own. Potentially this could have made pizza, rather than humans, the preeminent form of intelligent life in the known universe.

Thinkers such as Richard Dawkins see the evolutionary value of intelligence in its promotion of the survival and reproduction of a species' genes. Pizza found an alternative by entering into its dependency on humans, who gladly overtook measures to ensure its reproduction, which likely led to the creation of new social structures. The increase of this dependency over time ultimately restricted the evolution of pizza to the path that has produced the species we know today. But this notion is somewhat speculative.

Preliminary data suggest that it may be possible to push the knowable ancestry of pizza back even farther, to a point at which the last common ancestor diverged from other organisms such as crêpes, pancakes and burritos. We are currently digesting the data from that investigation, and anticipate publishing the results at a later date.

References

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Supplementary files, with data of ingredients per pizza, can be provided by the author on request.