The domestication of fermenting microbes: diversification and evolution

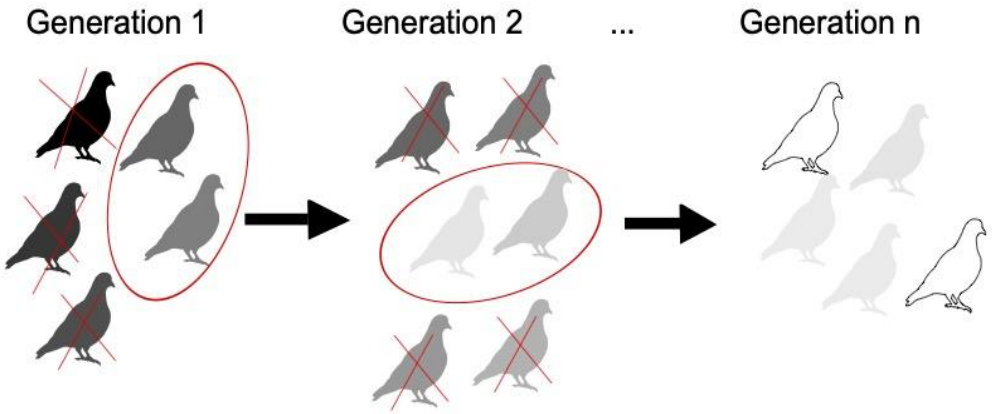
(Jeanne Ropars* and Tatiana Giraud*)

Wild carrot

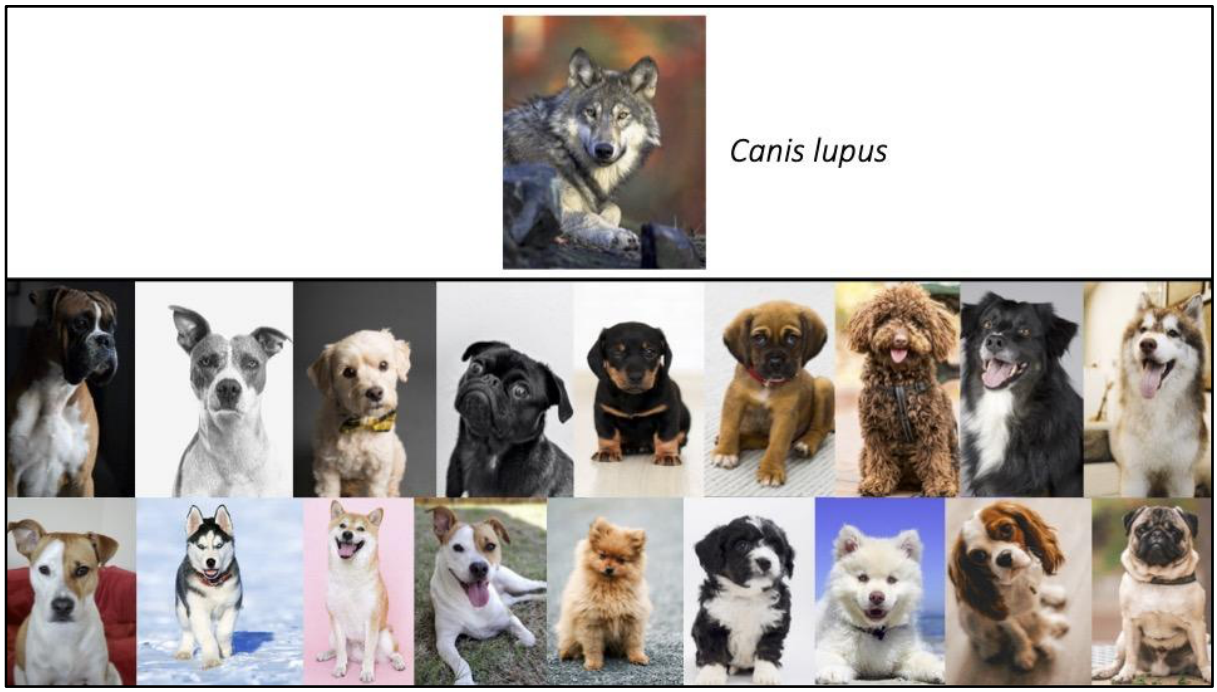
Humans have created these different colored carrots

What is domestication?

For millennia, we humans have domesticated many animals for different purposes: to eat them (for example: chickens, pigs, cows, sheep), to eat or use what they produce (milk from cows and goats, eggs from chicken, wool from sheep), to adopt them as pets (dogs), to take advantage of their strength or services (horses for field work and carrier pigeons). We have also domesticated many plants and trees, such as maize, wheat, carrots, roses, apples, apricots, strawberries, tomatoes, cotton... From wild organisms, humans have succeeded in generating new life forms, by strongly selecting particular traits. Let us take the example of pigeons: by selecting the whitest individuals, generation after generation, and by crossing them together, we were able to obtain doves.



Humans have also generated an amazing variety of dog breeds by selection:



What about microbes, those organisms invisible to the naked eye? Are there any domesticated microorganisms?

Is it possible to similarly domesticate microorganisms? The answer is yes! Humans were also able to select specific features, generation after generation, of fungi, to improve our food system. We have plenty of examples of domesticated microorganisms selected by humans for their ability to ferment food, to produce antibiotics such as the penicillin, to produce bioethanol or pigments, or simply for eating them.

The yeast *Saccharomyces cerevisiae* is used for making beer, bread, wine and also to produce bioethanol. The molds *Aspergillus oryzae* and *Rhizopus oryzae* are used for making Asiatic products such as miso, soy sauce and tempeh. Two *Penicillium* species are used for making cheeses, *Penicillium camemberti* for Camembert and *Penicillium roqueforti* for blue cheeses such as Roquefort. Another *Penicillium* species (*Penicillium rubens*) is used to produce penicillin, the famous antibiotic used against otitis in children. Pigments are produced by the fungus *Trichoderma reesei*. We also eat domesticated mushrooms, such as button mushrooms or shiitakes. All these microorganisms have been domesticated, that is, they are now different from their wild ancestors because humans have selected particular features and have thus modified them.

How did domestication happen in microorganisms?

Even if these organisms are microscopic, the process is quite similar to the domestication of dogs from wolves, generating new life forms and a diversity of breeds, by strong human selection for particular traits (different appearances and behaviors; see image above).

The white and fluffy mold which covers soft cheeses such as Camembert and Brie is the result of the selection of a single fluffy albino individual in 1898 from an unfluffy blue-grey ancestor. Bries were indeed blue until the middle of the 20th century (see the painting below), and a white mutant mold was selected because it appeared more appetizing.

Microorganisms are not like animals, in the sense that we do not need to 'breed' them by crossing two parents to obtain new individuals; we can just cultivate the same individual continuously, selecting the traits we desire when they appear, and further propagating the best individual that arises! However, this cannot last too long: if we only cultivate a single individual, it becomes less able to adapt to new conditions and soon the genetic material even degenerates. This is therefore not sustainable: genetic diversity is required for adaptation to new conditions and to avoid degeneration.

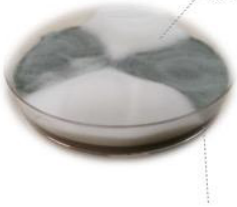
There is another mold found on cheeses, named *Penicillium biforme,* which is a very close cousin of *Penicillium camemberti.* You can find it on fresh goat cheeses in the form of little blue spots. These two domesticated species, *Penicillium camemberti* and *Penicillium biforme,* display advantageous characteristics for cheese ripening compared to their wild cousins: they are whiter (more appetizing!), grow faster on cheese (we want a fully white Camembert maturing fast!), do not produce any more certain toxins potentially dangerous for humans (we want to eat healthy cheeses!), and have a better ability to exclude other fungi that can spoil our cheeses (we don't want blue mold on our beautiful white Camembert).

Even more surprisingly, scientists discovered that humans have generated different varieties of microorganisms, like we did with the different dog breeds! There exist two varieties of *Penicillium camemberti* with very different appearance and flavor, that seem to be associated with different types of cheese: one variety for Camembert and Brie, white and very fluffy, and another for Saint Marcellin-like cheeses, grayer and less fluffy.

Bries were blue before 1898!

Symphonie des fromages en brie majeur;
Nature morte au fromage
Marie-Jules Justin, 1888

Penicillium camemberti, the white and fluffy mold selected in 1898 for making Camembert and Brie



Penicillium biforme, the blue-grey mold found on fresh goat cheeses

The same thing occurred for the yeast used for making beer, bread or wine: by selecting specific traits for optimizing yeasts for these different fermentation processes, humans have obtained various varieties of *Saccharomyces cerevisiae*, one for bread, and one for each type of alcohol, and even for different types of beer!

However, impoverishing the diversity by selecting a very small pool of individuals, or even a single individual, as in *Penicillium camemberti,* leads to degeneration, a well-known process in domesticated organisms. This has dramatic consequences for the persistence of domesticated species. Bulldogs for example have been too strongly selected and they have respiratory problems and females are unable to give birth without assistance. This is also the case for bananas: we are cultivating a single individual worldwide; imagine a pathogen able to kill this banana individual, it could kill all bananas worldwide! The same is true for fungi: the mold *Penicillium camemberti* cannot produce enough spores anymore, so cheesemakers have difficulties making their cheeses.

In conclusion, it is crucial to maintain diversity to cope with environmental changes and pathogen attacks, even in our dishes!

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