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# The Evolution of Capsaicin in Chili Peppers

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## ABSTRACT

This review paper will cover the role of capsaicin in the evolution of chili peppers and analyze the evolutionary advantages. Subsequently, the early evolutionary origins of this chemical deterrent are also recognized and how this may apply to the medical field, in terms of treatments. The role of natural selection as well as selective breeding are covered and how chili peppers have spread across the world over the years is studied. Finally, this paper looks at how innovation and technology has accelerated the evolution of these peppers, with new varieties that satisfy consumer preferences.

## Why Capsaicin?

Chili peppers have been bred for millennia [1]. The main biological component that gives these chili peppers their spicy taste is capsaicin [2]. Capsaicin evokes a burning sensation when organisms consume chili peppers. The evolution of capsaicin can be linked to the behavioral adaptations of mammals and how they have avoided consuming these plants. Certain adaptations have allowed mammals to be immune to the chemical damage that capsaicin can cause [3]. By researching this topic, a suitable understanding can be brought about where it can provide information about the evolution of capsaicin and its importance in ecological systems. Additionally, this review paper will draw conclusions about how capsaicin originated and what selection pressures were present for this adaptation to appear.

This article aims to focus on how capsaicin had evolved amongst chili peppers and its importance in biological systems. Moreover, this paper explores the diversification of peppers and how these peppers spread throughout the globe. In terms of how this paper will progress, the article will first proceed with the origins of capsaicin and how it has evolved over history. External factors will also be considered, such as artificial breeding and changes in the environment, and how much of an influence it has had. The role of humans in artificial breeding is too significant to ignore, as we are heavily involved with the evolution of capsaicin within chili peppers. All in all, understanding how capsaicin has evolved can help humanity gain knowledge that can later be used for our benefit.

## Section 1: Origins of Capsaicin

Capsaicin is the component in chili peppers that makes them spicy. It is a chemical that brings a “burning sensation” when consumed. Naturally, capsaicin is found in the seeds of plants that are part of the Capsicum family. While it is usually present in spicy food, capsaicin has other uses outside of taste. Muwen Lu, a researcher at the Guangdong Provincial Key Laboratory in Guangzhou, China, articulates how capsaicin possesses an “analgesic effect”. This effect is later explained as a sort of treatment for persistent pain that humans can be at risk to as well as having an “antioxidant effect” as capsaicin is able to shield biological organs from harmful oxygen species [4]. The concentration of capsaicin within these chili plants is directly correlated to the presence of nutrients within the soil. A nutrient-rich medium for chili plants to grow on yields higher capsaicin levels as the plant has more resources to work with [5]. Nutrients, especially magnesium, potassium, and nitrogen, play a key role not only in the growth of the plant but as well as the increase of capsaicin in these plants as well. Plants that lack such nutrients would shrink and experience limited growth. Moreover, capsaicin is known to be an anti-obesity and anti-cancer remedy to patients that may experience these problems [4]. However, it is important to acknowledge that capsaicin itself is a chemical irritant and that consuming a considerable amount would bring consequences to the human body. Extreme amounts of capsaicin can cause nausea and abdominal cramps [25].

Capsaicin is a chemical unique to the *Capsicum family* and creates agitation when it meets mammalian tissue. In the natural world, it dissuades predators from consuming the plant and serves as an adaptation for defensive purposes [6]. Furthermore, the defense of capsaicin in these chili plants also applies to pathogens and how the pungency of these chili plants is a result of natural selection of predation/disease [7]. The benefit of a plant having a strong concentration of capsaicin increases the chances of surviving a pathogen attack/predation compared to a plant that does not contain capsaicin. This explains how over time, these capsaicinoids**,** a family of plants that evolved to produce capsaicin, have successfully adapted to their environmental pressures. Capsaicinoids are positively selected in environments that contain high predation and high disease fallouts.

In terms of evolutionary history, the exact time in which capsaicin evolved within the *Nightshade* family is hard to decipher. As a result, several theories have tried to answer the phylogenetic background of the *Capsaicum* family. The most prominent one is that chilies evolved from Latin America. However, this theory isn't fully supported. The known facts are that the genomes of these chilies are 4.9 billion base pairs and that there is one specific unknown origin. Through genetic analysis, it is also known that the millions of chili varieties we see today are due to seed dispersal through avian species 20 million years ago [8].

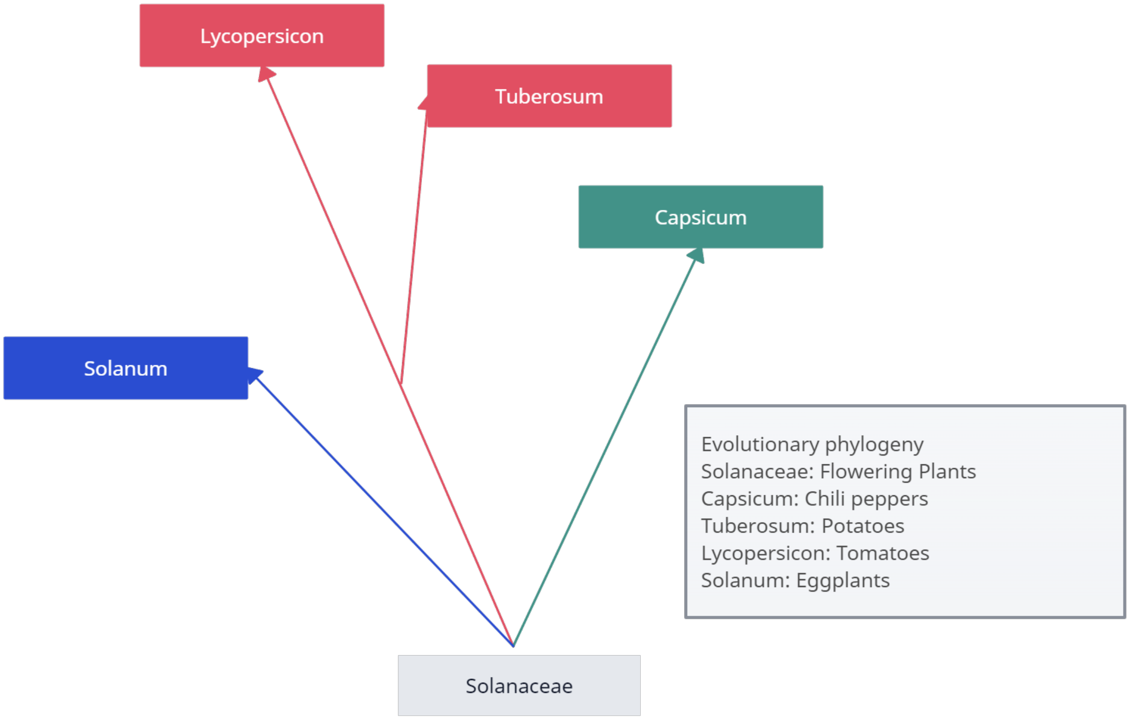

***Figure 1*** explains the evolutionary links between capsicum (chilies in this paper's context) to other origins of plants that are closely related to capsicum plants [8].

***Figure 1*** demonstrates the relatedness of capsicum plants (plants that contain capsaicin) to other plants and its ancestral plants as well. Solanum (eggplants) are seen to be the most closely related genus to capsicum plants in this diagram with their most recent common ancestor being *Solanaceae* (flowering plants). After the first split, *Solanaceae* further splits into *Lycopersicon* (tomatoes) and *Tuberosum* (potatoes) [8]. Members of the "*Solanaceae*" consist of 12 chromosomes but vary in terms of genome sizes due to SNPs and different levels of genomic expression [9].

SNPs, small nucleotide polymorphisms, are small genetic variations caused by a nucleotide substitution, which can change gene expression.

In addition, the Korean chili variety diverged from the Mexican chili variety about 1.7 million years ago. This displays how these chilies from different continents do share some evolutionary history and follows a divergent evolutionary model (when considering only these two chili varieties). One limitation of this model was that there wasn't genetic data that this paper displayed. This discourages the comparison of chilies based on their genes and where they are regionally found. Further studies should incorporate data if possible as it would give greater depth on the exact evolutionary path that chilies had appeared through.

While capsaicin is traditionally consumed, humans have recently found beneficial properties that capsaicin contains that can be applied in the medical field. Commonly, capsaicin has been used to treat neuropathic pain and is recognized as an analgesic. Capsaicin targets certain cell pathway receptors that allow it to be effective when minimizing pain in patients. The TRPV1 receptor is one such receptor that capsaicin attaches to and allows such pain treatments to target this receptor [10]. Another study found that capsaicin can reduce pain in patients by up to 40%, displaying the effectiveness of capsaicin in neuropathic pain treatment [11]. In both studies, capsaicin is described as a ligand, which initiates a chemical pathway resulting in pain relief.

The therapeutic element of capsaicin extends beyond its initial interaction with the TRPV1 receptor. Upon binding to TRPV1, capsaicin initiates a cascade that modulates pain perception by causing an influx of calcium ions into the neuron, desensitizing pain receptors and reducing the transmission of pain signals sent to the brain [24].

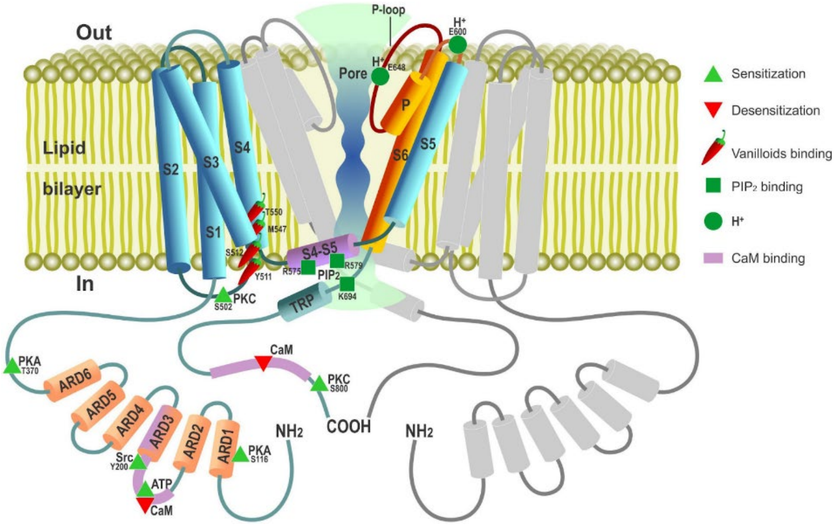

***Figure 2*** displays the TRPV1 pathway and its involvement in cell signaling pathways [24].

***Figure 2*** explains how the TRPV1 receptor is involved with cell signaling pathways. This receptor allows capsaicin to bind to the ligand binding site, causing a biochemical cascade. This cascade eventually results in an action potential that causes a sensation of spiciness. In addition, the ability of capsaicin to bind to such receptors allows researchers to manipulate it to their benefit. For example, with the consumption of capsaicinoids, capsaicin can bind to the active site of the TRPV1 receptor that is present in the oral cavity. Moreover, this receptor is connected to the sensory neurons that detect "spiciness". When capsaicin binds to the receptor, it increases the amount of energy used by the individual by increasing intracellular calcium leading to loss of body fat [12]. This loss in body fat contributes to the effectiveness of using capsaicin as an anti-obesity treatment. Similarly, the energy expenditure that capsaicin can cause is similar to that of caffeine, a drug found in coffee [13]. Capsaicin is also able to treat arthritis pain by its anti-inflammatory properties and neuralgia. Neuralgia is a sharp pain due to the irritation of a nerve. The biochemical pathway that capsaicin follows is able to inhibit neuralgia, making it a pain reliever [23].

## Section 2: Evolutionary History of Capsaicin

Chili peppers originated about 14 million years ago in Central America. This ancestral plant had capsaicinoid properties that allowed it to have an evolutionary advantage against its predators. Capsaicin is a chemical deterrent that causes a burning sensation to creatures that consume it. This discouraged animals from eating such plants. However, avian species were immune to capsaicin as they were unable to taste the chemical. As a result, birds were able to promote seed dispersal in the chili plants, facilitating the germination of chili plants across the Americas and eventually, to other parts of the globe. Humans, unlike most animals, were not deterred when consuming capsaicin. As a result, they sought to domesticate these chili peppers in the New World, and this brought considerable variation into the chili population [14]. The domestication of these chili peppers was moved to other parts of the New World, and this allowed speciation events to occur within these local populations. This brought about many varieties within the chili population.

Originally, there were a handful of chili peppers that had begun to grow in Central America. These species were the ancestral species that had initially begun to appear and provided the backbone of variation that we see in today's chili peppers. These ancestral peppers were smaller in size and contained smaller seeds as well. Natural selection allowed for the spread of these peppers. However, the majority of variations that would lead to new species of chili are mostly due to artificial selection by humans. For example, the size of peppers didn't drastically change as much until humans started to selectively breed for larger peppers [15]. Another important catalyst of chili seed dispersal is the transcontinental voyages that explorers took to the Americas. These chili plants were brought back to Europe and started to spread across Europe and into Asia [14]. The chili plants that were grown there were domesticated and selectively bred to render the best traits. Different varieties of chilis started to emerge as these peppers were crossbred for a more desirable pepper in terms of size, color, and pungency.

In terms of a specific known origin of the artificial breeding of chili peppers, one such group were the Native Americans. Native Americans have bred chili peppers 6000 years ago [15]. With this selective breeding over generations, chili peppers have been able to propagate into different regional varieties. In terms of shape, chilies have been bred to conform to a certain shape.

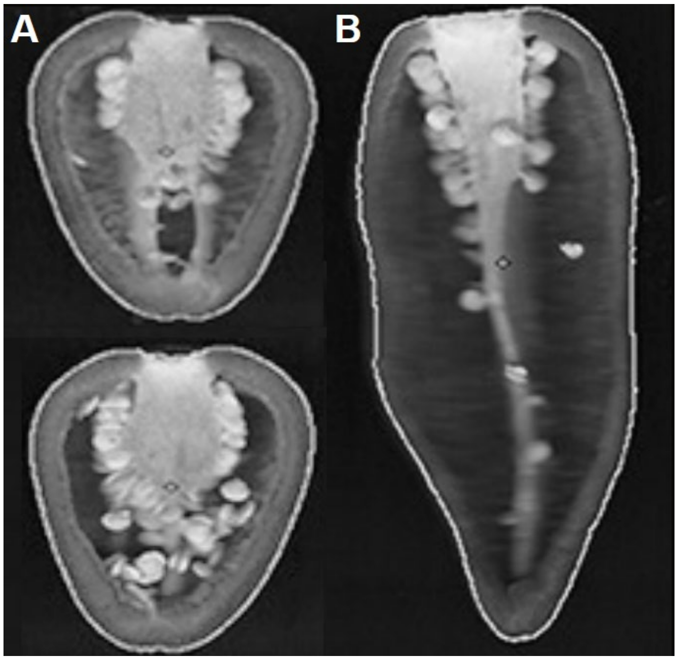

***Figure 3***. [A] Wild type C. annuum pepper. [B] Bred, elongated C. annuum pepper [22]

While some may be cuboidal, others are long and thin. ***Figure 3*** compares the shape of peppers from the same species. In ***Figure 3***, we can see an example of the results of selective breeding in peppers. While the [A] wild-type C. annuum pepper is smaller, spherical, and shorter, the [B] artificially bred C. annuum pepper is longer and more cylindrical. One explanation for shape is a result of selective breeding that contributes to changes in chromosome 10 in the genome of the capsicum family. Additionally, chilies that take an "ellipse-like shape" are correlated to a changed chromosome 11 that consists of SNPs whereas circular chili plants are also due to a SNP, this time on chromosome 3 [16]. These genetic modifications can be explained by the specific breeding of chili peppers by farmers to obtain certain shapes of these plants and how changes in phenotype can result in changes in the genotype of these plants.

The pungency of these chili plants are an important trait that have been selected for by breeders over centuries. Through selective breeding, new genes correlated to pungency were created with the duplication of existing genes [9]. Consumer-driven preferences create new chili peppers varieties that are bred based on size, pungency, and color. These multigenic traits that code for this unique variation is used through the admission of SNPs, creating peppers that can be immune to their environment. Through the use of SNPs, new chili pepper variations can be made. For example, larger non-pungent peppers (through SNP insertion) can be made through this genetic manipulation [17]. Similarly, the selective breeding of chili peppers based on pungency can also be done through the genomic analysis of these plants. Genetic markers can be used for areas of the genome that are responsible for the capsaicin within those plants and as a result, breeding peppers with the favored features would eventually result in more pungent peppers over time [18]. This resulted in spicier peppers over time, and this has rocketed over the past 30 years, with more pungent peppers being bred quicker than ever before [9].

While natural selection and selective breeding have created many of the chili pepper varieties we see today, genetic engineering allows such changes to be instant rather than taking a longer time compared to previous methods. Consumer pressure on capsicum plants has helped fund new agricultural technology. This agricultural technology allows for shorter harvest duration and larger fruits for the goal of a greater yield. Manipulating the genetic code within these plants to the benefit of the market is directly causing chili plants to evolve. Artificially selecting these traits results in a higher yield of larger chili plants [19]. Moreover, having a good understanding of the genome of these plants allows genetic engineers to create more resilient peppers that are able to withstand disease and other limiting factors that can affect their growth. By testing sample populations on how desired traits may propagate within those samples, those genetic markers/changes can be implemented in mass. This can lead to better chili crops for consumption [20].

These new varieties are also being tested on their pungency and breeders are actively trying to create hotter peppers. By testing how much water is required to dilute the capsaicin content within a variety of peppers, breeders can actively test the pungency of peppers by ranking them on the Scoville scale. A higher nitrogen concentration within the plants increases the pungency of these peppers. Other factors such as weather, temperature, and environment are less important but must also be considered. Highly pungent peppers that have been artificially bred, such as the Carolina Reaper, have been commercialized. Having a 1.6 million Scoville unit ranking, it is the world's most pungent pepper. Numerous other breeders are actively trying to create a more pungent pepper that can also be popularized in today's markets [21]. The innovation and technology present today is actively shaping the way chili peppers are evolving.

## Conclusion

This review paper articulates the evolutionary importance of capsaicin and its importance in the modern world. The ancestral history of these peppers are shown to be related to one geographical point in Central America. These peppers were later dispersed through avian species. Humans have had a significant role in the diversification of these peppers as selective breeding has created new varieties of peppers based on size, shape, color, and pungency. Similarly, the use of capsaicin for humanity's benefit is clear as capsaicin works as an antioxidant, which contains anti-inflammatory and anti-cancer properties. Furthermore, new innovations and technology have provided engineers with the framework to create peppers that are more adaptable to their environment and a higher yield to satisfy the market demand for these peppers.

The framework of this review paper was based on several questions we initially proposed. Answering these questions sequentially, 'Was the evolution of capsaicin a result of predation?' After gathering literature, it can be confidently said that capsaicin evolved as a result of predation of mammals. The chemical deters mammals from consuming the plant. However, it doesn't deter birds as it promotes seed dispersal. This would explain how the seeds have dispersed across Central America and to other parts of the world. Another question that we asked was 'What are some of the nutrients responsible for the production of capsaicin in plants?' The paper talks about how certain elements, such as nitrogen and magnesium, have a strong correlation to capsaicin concentration within that plant [21]. A lack of these nutrients inhibits plant growth while also preventing capsaicin from being an effective deterrent. Finally, 'Did Capsaicin follow a divergent or convergent evolutionary model?' This paper gathered literature that proves that the Korean chili variety is more closely related to the Mexican chili variety compared to other Asian chili varieties [9]. However, actual genetic sequence data that directly compares the relatedness between chili species was not found in this paper and serves as a limitation. Going forward, it would be beneficial to have a review paper that further enhances existing literature by offering data to precisely determine the evolutionary model.

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