Review

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Functional Morphology and Ecological Role of Therizinosaurs: A Focused Review

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Abstract: Therizinosaurs, a unique clade of theropod dinosaurs, are characterized by their distinct morphological features and enigmatic ecological role. This review provides a comprehensive analysis of the functional morphology and ecological significance of these remarkable dinosaurs. Therizinosaurs are distinguished by their elongated, often curved claws, robust postcranial skeletons, and herbivorous diet, which starkly contrasts with their carnivorous theropod relatives. We explore the evolutionary implications of their morphology, focusing on adaptations such as their specialized feeding apparatus and limb structure. These features suggest a complex interplay between their herbivorous lifestyle and ecological niche. The review synthesizes recent findings from fossil evidence, including detailed studies of cranial and postcranial anatomy, to elucidate the functional mechanisms behind their unique adaptations. Additionally, we discuss the broader ecological role of therizinosaurs within their Mesozoic ecosystems, highlighting their interactions with contemporaneous flora and fauna. By integrating paleontological data with comparative anatomy and ecological modeling, this review aims to shed light on the evolutionary trajectory of therizinosaurs and their impact on our understanding of theropod diversity and adaptation. This focused review contributes to a more nuanced appreciation of therizinosaurs' place in dinosaur evolution and their adaptive strategies in prehistoric environments.

Keywords: Therizinosaurs; functional morphology; ecological role; theropod dinosaurs; elongated claws; herbivorous diet; evolutionary implications; fossil evidence; cranial anatomy; postcranial anatomy; Mesozoic ecosystems; Therizinosaurus cheloniformis; Falcarius utahensis; claw structure; feathered bodies; defensive mechanisms; skeletal structure; feeding behaviors; mechanical analyses; plant-feeding; semi-arid environments; floodplains; vegetated landscapes; body mass evolution; Late Cretaceous; predation; anatomical diversity

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Functional Morphology and Ecological Role of Therizinosaurs: A Focused Review

Therizinosaurs are a unique group of theropod dinosaurs that were primarily herbivorous, setting them apart from their carnivorous relatives. Initial therizinosaurs like *Falcarius utahensis* were small and bipedal, but they gradually evolved into larger, more specialized forms such as *Therizinosaurus cheloniformis*. While *Falcarius utahensis* is estimated to be around 2-3 m long, *Therizinosaurus cheloniformis*, one of the most well-known therizinosaurs, measures approximately 4-5 m tall when upright, 10-12 m in length, and 3-5 metric tons in weight. This massive disparity in size and appearance suggests specialization for certain functions and ecological roles for the therizinosaurs.

Key characteristics, especially of the larger therizinosaurs, include the large, curved claws that could reach up to sizes of 1 m in length, small and leaf-shaped teeth designed for their herbivorous diet, the presence of feathers, long necks, beak-like mouths, and bulky bodies. Attributes like these may have proven to be useful for their herbivorous lifestyle, reaching tall heights to obtain food, as well as defending against potential threats. These features also have not been observed in any other

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group of dinosaurs throughout the entirety of the Mesozoic Era. Additionally, they propose some insights into the potential ecological roles that therizinosaurs had in their respective environments.

In this literature review, I will discuss the functional morphology and ecological role that therizinosaurs played in their environments. I will begin with an in-depth analysis of the various morphologies of certain features of therizinosaurs, such as their long and curved claws. Then, I will investigate the therizinosaurs' ecological roles, such as their mechanisms of defense and method of herbivory. Finally, I will conclude with an overall examination of the unique features that allowed therizinosaurs to lead successful lives in their respective ecosystems.

Functional Morphology of Therizinosaurs

To understand therizinosaurs, we must first analyze the functional morphology of therizinosaurs and the purposes of specific characteristics of their bodies. By examining therizinosaurs' anatomical adaptations, such as their unique claw structure, feathered bodies, and herbivorous dental traits, we can infer their feeding behaviors, defensive mechanisms, and overall lifestyle. Detailed studies of their skeletal structure and muscle attachment sites provide insights into their movement and posture, while analysis of wear patterns on teeth and claws can reveal their dietary preferences and foraging strategies. Through this comprehensive approach, we can better understand the functional significance of their unique adaptations and how these remarkable dinosaurs utilized their physical traits in their daily activities.

A study conducted by Weishampel et al. (2004) investigated the morphology of various aspects of the therizinosaur body plan. For instance, it was determined that therizinosaurs had relatively small skulls with a shortened snout and an expanded narial region. Additionally, the premaxilla was edentulous and formed a beak-like structure. In terms of dentition, the teeth of therizinosaurs were small, with coarse serrations or denticles. They were leaf-shaped and laterally compressed, indicating a herbivorous diet. The teeth were set in a relatively low and elongated dental battery, also observed by Pu et al. (2013), Zanno (2010), and Kirkland et al. (2005). For vertebrae, the cervical vertebrae were elongated and opisthocoelous (convex in front and concave behind), allowing for extensive neck flexibility. They exhibited prominent neural spines and extended articular surfaces for muscle attachment. Furthermore, the dorsal vertebrae had relatively low neural spines and were amphicoelous (concave on both ends), designed to support a large, barrel-shaped body. Analysis was also performed on the forelimbs and manual claws. It was found that the humerus was robust, with a prominent deltopectoral crest, suggesting strong forelimb musculature. Both the radius and ulna were elongated and bowed, supporting the functionality of the long forelimbs. The hands were large, with three functional fingers. The second digit bore an enormous, laterally compressed, sickle-shaped claw, which could reach lengths of up to 1 meter in *Therizinosaurus*. These claws were highly specialized, with a deep, recurved shape, indicating potential uses in foraging, defense, or intraspecific interactions, also suggested by Clark et al. (1999). The claw sheath was keratinous, significantly increasing the effective length and curvature of the claws. In therizinosaurs, the pelvis was broad and platelike, with an anteriorly expanded ilium, providing a wide attachment area for muscles and suggesting support for a large gut, also noted by Paul (1984). The femur was robust and straight, with a well-developed fourth trochanter for muscle attachment. Both the tibia and fibula were robust, with the tibia being slightly longer than the femur, indicating a strong and stable hindlimb structure. The feet were broad, with three weight-bearing digits (II, III, IV), and the phalanges were short and robust, reflecting a plantigrade posture. For the tail region, the caudal vertebrae were relatively short and decreased in size distally. Hence, the tail was likely not used for balance or locomotion but may have played a role in display or defense. Finally, evidence from related species suggests the presence of a primitive feather covering or filamentous integument, which could have served purposes such as thermoregulation, display, or protection.

Extensive examination of the therizinosaur jaw by Lautenschlager (2015) used biomechanical analysis to determine how its musculoskeletal structure influenced feeding behavior. This model involved reconstruction of the jaw with a comparison to modern archosaurs such as crocodiles,

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allowing for a detailed analysis of muscle attachment sites and muscle size. It was discovered that the jaw muscles in therizinosaurs, particularly the m. adductor mandibulae externus and the m. pterygoideus, were adapted for a herbivorous diet, allowing for strong, repetitive chewing motions. This musculature was robust, supporting powerful jaw movements for processing plant material. Therizinosaurs exhibited limited cranial kinesis, similar to other theropods. The skull structure was relatively rigid, providing a stable platform for the jaw muscles to operate efficiently during feeding. The study also estimated the bite force of therizinosaurs using digital modeling. The bite force was found to be around 600 N, significantly lower compared to large carnivorous theropods like *Tyrannosaurus rex*, which had an estimated bite force of 35000 N. This lower bite force is consistent with their herbivorous feeding habits, which did not require the high bite forces needed for bone-crushing.

Overall, it is reasonable to conclude that the morphology of therizinosaurs is a distinguishable aspect of this group. Armed with large claws that could have been used in foraging and defense, therizinosaurs also had their cranial morphologies fit for their special usage in herbivory. Their extensive musculoskeletal system also allowed for strong structural support and locomotion.

Ecological Role of Therizinosaurs

Since we have now investigated the morphology of therizinosaurs, we must now examine their ecological roles. These would include defense against potential threats, as well as their role in herbivory and plant-feeding. Once attaining a substantial understanding of the ecological roles of therizinosaurs, we will be able to relate morphology with this aspect to gain a deeper realization of the therizinosaur lifestyle.

Therizinosaurs like *Therizinosaurus cheloniformis* lived in a wide variety of environments. One such environment was semi-arid to arid, such as the deserts of Mongolia. The Djadochta Formation, where many therizinosaur fossils have been found, was a desert environment characterized by sandy and rocky conditions, with sparse vegetation. Another type of environment inhabited by therizinosaurs was categorized by floodplains and river systems. Fossils of therizinosaurs from the Huadian Formation in China suggest they lived in environments that included these regions. These areas were likely characterized by more abundant vegetation compared to arid environments, providing a suitable habitat for herbivorous dinosaurs. The other observed environment for therizinosaurs was lush and vegetated landscapes. In North America, *Falcarius utahensis* is known from the Cedar Mountain Formation in Utah, which was a more lush and vegetated environment compared to the arid settings in Mongolia. This formation was characterized by a subtropical to temperate climate with abundant plant life. The ability to thrive in such varied environments indicates therizinosaurs' adaptability to various ecological conditions during the Late Cretaceous.

A study by Zanno & Makovicky (2013) examined the evolutionary patterns of body mass in herbivorous theropod dinosaurs. They focused on whether there was evidence for directional evolution in body mass among these dinosaurs. No evidence was found that supported a consistent directional trend in body mass among herbivorous theropods, suggesting that body mass in these dinosaurs did not show a clear trend toward increasing or decreasing over time. These findings challenge some previously proposed models of evolutionary trends in theropods, proposing that body mass evolution in these dinosaurs may have been more influenced by ecological factors and lineage-specific traits rather than a simple directional trend.

Zanno & Makovicky (2011) provide valuable insight into the various ecological roles that therizinosaurs had in their respective environments. One aspect of this involves the habitats of therizinosaurs. In habitats such as floodplains, river valleys, and forested areas with abundant vegetation, therizinosaurs often had adaptations for processing a wide range of plant materials. This included features like leaf-shaped teeth and beak-like structures. Larger body sizes and robust limb structures helped them access and process large volumes of vegetation, allowing them to act as large-scale grazers or browsers in dense vegetation. In other habitats such as arid and semi-arid regions, theropods like *Therizinosaurus* evolved adaptations to handle limited plant resources. They may have

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had more robust teeth or specialized beaks to process tougher plant material, acting as specialized browsers. Overall, adaptations in body size and shape in therizinosaurs were directly related to the functional roles these theropods played in their respective environments. Larger body sizes often correlated with grazing behaviors, while smaller sizes might align with browsing in more constrained habitats.

As the therizinosaurs lived during the Late Cretaceous, they would have encountered numerous threats. The most significant of these threats was likely carnivorous theropods aiming to obtain a meal. This was another probable reason behind the morphology of therizinosaurs. Their large size and immense, curved unguals would have deterred potential predators by appearance alone, and for those that continued to pose a threat, most likely would have inflicted severe damage and tearing of flesh.

Therefore, therizinosaurs likely played the ecological role of herbivores, but their physical characteristics would have also enabled them to properly defend themselves from potential threats. Difference between therizinosaur species was likely the result of varying environmental pressures in their respective ecosystems. For instance, larger body sizes often correlated with grazing behaviors, while smaller sizes might align with browsing in more constrained habitats. Additionally, different cranial structures and types of environments display the therizinosaurs' versatility in adapting to various regions.

Conclusions

Limitations on Existing Research

While the existing research on therizinosaurs provides significant insights into their unique morphology and ecological roles, it has several limitations. First, the fossil record for therizinosaurs is relatively sparse and incomplete, which restricts comprehensive understanding of their anatomical diversity and evolutionary history. Many reconstructions and functional interpretations are based on a limited number of well-preserved specimens, which may not fully represent the variability within the group. Second, there is a heavy reliance on comparative anatomy and biomechanical modeling, which, although informative, involve a degree of speculation and assumptions that may not always be accurate. The ecological interpretations are often extrapolated from modern analogs, which might not precisely reflect the behaviors and interactions of these ancient creatures. Finally, there are gaps in knowledge regarding the specific environments therizinosaurs inhabited and their interactions with contemporaneous flora and fauna, which are crucial for a thorough understanding of their ecological roles. These limitations highlight the need for more research in order to deepen our overall understanding of therizinosaurs.

Takeaway

Therizinosaurs, with their unique blend of features, played a vital ecological role as herbivorous theropods. Evolving from small, bipedal ancestors to large, robust species like *Therizinosaurus cheloniformis*, they developed specialized adaptations including massive claws, small leaf-shaped teeth, and elongated necks, which facilitated their plant-based diet and provided defense against potential threats and predators. Their presence in varied environments, from deserts to floodplains, highlights their ecological versatility and adaptability. These dinosaurs were well-equipped for herbivory with powerful jaw muscles and a low bite force suitable for processing vegetation, while their large claws and sturdy builds offered formidable protection. Overall, therizinosaurs were successful herbivores, adept at navigating diverse habitats and effectively balancing foraging and defense.

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