A Comprehensive Review of Reptile Meat as an Alternative Protein Source: Nutritional Composition, Safety Concerns, Environmental Impact and Welfare Issues

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Abstract
This review investigates the feasibility of reptile meat as an alternative protein source in the context of rising global protein demand and the need for sustainable food systems. It synthesizes current knowledge on edible reptile species (crocodiles, turtles, snakes and lizards), their farming and geographic distribution and the key nutritional, safety, environmental and welfare aspects associated with their use for human consumption. Available data indicates that reptile meat, particularly from crocodiles, snakes and some turtles, is characterized by high protein content, favourable fatty acid profiles (including essential n-3 and n-6 polyunsaturated fatty acids) and appreciable levels of essential amino acids and minerals, making it nutritionally comparable or superior to conventional livestock meats. However, important concerns persist regarding microbiological and chemical hazards, parasites, traceability and the role of reptile farming and harvesting in overexploitation, biodiversity loss and animal welfare challenges. This review highlights substantial regional differences in cultural acceptance and regulatory oversight and identifies major gaps in nutritional composition data, risk assessments, legislation and welfare guidelines for reptile farming and reptile meat safety and quality. Overall, reptile meat may contribute to protein diversification, but its broader commercialization should be contingent on robust food safety management, conservation-compatible sourcing and species-specific welfare standards.

Keywords: environment, food safety, nutritional composition, reptile farming, reptile meat, welfare.

1. Introduction

Major challenge for world economy and food sector is rapidly growing population. Although projections wary, it is suggested that the global population will reach roughly 12.7 billion people in 2080 [1]. This population growth will not be uniform, with regions such as Africa, North America, Australia and South and Central Asia increasing rapidly in numbers, while Europe, Russia and China population growth is expected to slow down (a reflection of changing fertility rates, international migration and enhanced life expectancy) [2]. Feeding the world's rapidly increasing population will require a sustainable source of proteins that is integrated within food production systems [1]. Forecasts indicate a 1.4% rise in meat consumption, emphasizing the urgent need to identify and develop protein sources that can support global dietary demands [3]. Currently, the major sources of meat consumed worldwide, apart from aquatic species and insects, are poultry, pork, beef and small ruminants [3]. Poultry represents the most widely consumed meat, followed by pork. Beef comes next in terms of global consumption, with meat from small ruminants being consumed to a lesser extent [1]. With projected population growth and increasing

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need for food a question is raised – which alternative sources of animal proteins (edible insects excluded) are easiest to be commercialized and integrated into existing food production systems to meet the growing demand for food. One alternative source of animal proteins that is currently present on the market is reptile meat. It is well documented that many exotic species, such as reptiles, have served as protein source for human populations around the globe for centuries [4]. Reptile meat is extremely important protein source for those populations that do not have access to meat from domesticated animals or sea food [4], such as tropical and subtropical areas [5]. In contrast, the consumption of meat from reptiles in the European Union (EU) and the United States (US) is considerably lower. In Europe, there is virtually no tradition of consuming reptile meat, although some exceptions do exist [6]. In the United Kingdom (UK), turtle soup was frequently consumed during the 19th and early 20th centuries, while in Spain the consumption of reptile meat was common during the 19th century [6]. Over the last 50 years, an increase in the consumption of dishes prepared from the reptile meat has been observed in developed countries [4, 7]. The growing interest and rising market demand for exotic animal meat have led to the commercial farming of edible reptile species [6]. In recent years, there has been a notable increase in the commercial farming of various reptiles (snakes, lizards, turtles and crocodiles) specifically for the purpose of producing meat and meat products [6]. This trend reflects a growing interest in alternative protein sources and the diversification of agricultural practices to meet evolving consumer demands [6]. On the other hand, commercial farming and the consumption of exotic animal meat have led to the overexploitation of certain reptile species in specific world regions, driving them to the brink of extinction [4,6,8,9].

This review article explores the feasibility of utilizing reptiles as an alternative protein source for human consumption. Where applicable, it will present comparative insights with other commonly consumed livestock species and edible insects. This review compiles and discusses all existing data related to safety concerns, the environmental impact, welfare issues and legislation associated with the farming of reptiles and the consumption of reptile meat.

2. Edible reptile species

Taxonomically, crocodiles are classified into three families: *Alligatoridae*, *Crocodylidae* and *Gavialidae* [10]. Worldwide several crocodile species are farmed commercially for obtaining meat for human consumption, including Nile crocodile (*Crocodylus niloticus*), freshwater crocodile (*Crocodylus johnstoni*), Siamese crocodile (*Crocodylus siamensis*), American crocodile (*Crocodylus acutus*), saltwater crocodile (*Crocodylus porosus*), American alligator (*Alligator mississippiensis*) and yacare caiman (*Caiman yacare*) [4]. Some edible crocodile species are shown in Figure 1. [4,7], while Figure 2. shows the global distribution of crocodiles [4].

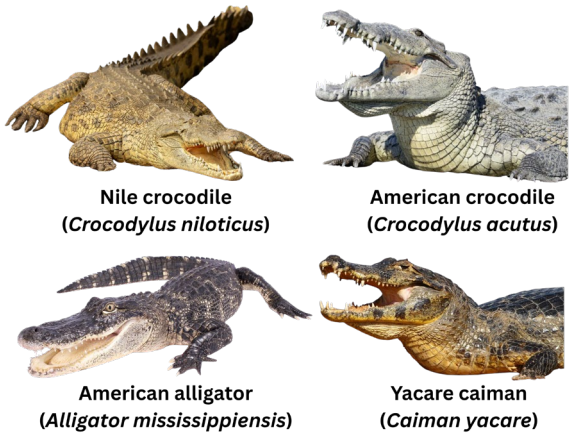

Figure 1. Edible crocodile species (adapted from Domínguez et al. [4]).

Consumption of crocodile, caiman and alligator meat is present mostly in Australia, Thailand, Africa, Brazil and the US [10,11]. The primary facilities and infrastructure dedicated to the breeding and farming of crocodiles in captivity are predominantly located in Africa and parts of Australia and Asia [10]. Among the various reptile species farmed for human consumption, crocodiles play a significant role due to their adaptability and the demand for their meat in different regions. The Nile crocodile is native to Africa and is widely reared across several countries, including Egypt, Madagascar, Kenya, Zimbabwe, Tanzania, Seychelles, Comoro Islands, South Africa, Israel, Indonesia, France, Japan, UK and Spain. This broad geographic distribution highlights the importance of crocodile farming in both African and international markets and, collectively, demonstrates the increasingly global nature of crocodile production for meat [4,12,13].

The freshwater crocodile is also commercially farmed in Australia, underlining the country's role as a key producer of crocodile meat [4]. The Siamese crocodile is primarily reared in Thailand and Cambodia, contributing to the diversity of farmed crocodile species in Southeast Asia [6,12].

Figure 2. Global distribution of crocodiles (wild and farm-raised) (adapted from Domínguez et al. [4]).

In North America, the American alligator is typically farmed in the southern US, particularly in Georgia, Florida, Texas and Louisiana, where suitable climatic and environmental conditions support commercial operations [4]. Central and South America caiman (*Caiman crocodilus)* is farmed from Mexico to Peru, while farming of yacare caiman is observed in Brazil, Argentina, Uruguay, Paraguay and Bolivia [13,12]. Saltwater crocodile is predominantly farmed in Australia, Papua New Guinea and Thailand, reflecting its adaptability to a range of environments in the Asia-Pacific region [13]. Alongside these species, hybrids resulting from the crossbreeding of saltwater crocodiles with Siamese crocodiles are also commonly bred [4,10]. These breeding activities have established Australia and Asian countries as principal hubs for commercial crocodile farming worldwide, reflecting the significance of these regions in the global market for crocodile meat and meat products [10].

The term "turtle" is commonly applied to all members of the order *Testudines* [4]. However, usage may vary according to habitat – freshwater species are often referred to as "terrapins", terrestrial species as "tortoises" and marine species as "sea turtles" [6]. Historically, turtles were hunted in their natural habitats and their meat was consumed. Although this practice has declined over the years, it still occurs in certain regions [6]. Among terrapins, a distinction is made between soft-shelled and hard-shelled species. Soft-shelled terrapins typically inhabit warm ponds, marshes, lakes and rivers, where they feed on crustaceans, small fish and snails, insect larvae, other small aquatic animals and seeds of marsh plants [14]. Their rapid growth rate and high annual reproductive output render soft-shelled terrapins particularly suitable and economically attractive for aquaculture [4,6]. The native distribution of soft-shelled terrapins includes China, Taiwan, Japan, Korea, Thailand and Vietnam [15,16,17,18]. Turtle meat, particularly that of the diamondback terrapin (*Malaclemys terrapin*), is also produced in aquaculture systems in the southern US [4,6,13]. The Chinese soft-shelled turtle (*Pelodiscus sinensis*) and the Brazilian tortoise (*Trachemys scripta elegans*) are among the most economically valuable turtle species in Asian markets [19,20]. Chinese soft-shelled turtle and Diamondback terrapin (*Malaclemys terrapin*) are farmed primarily for meat production [10]. Due to their high nutritional value and profitability, these species constitute important aquaculture species in Asia [21]. Among hard-shelled terrapins, the main farmed species include the Reeves' turtle (*Chinemys reevesii*) and the Chinese pond turtle (*Mauremys mutica*) in China, and the Chinese stripe-necked turtle (*Ocadia sinensis*) in Taiwan [10].

Other turtle species, such as the South American river turtle (*Podocnemis expansa*) and the yellow-spotted river turtle (*Podocnemis unifilis*), are present throughout many regions of the Amazon basin in Brazil, where they are widely consumed [11,13]. In South American countries, terrestrial *Testudines* (tortoises), including the yellow-footed tortoise (*Chelonoidis denticulata*) and the red-footed tortoise (*Chelonoidis carbonaria*), are also used as a food source [11]. In Madagascar, the radiated tortoise (*Astrochelys radiata*) is consumed despite its status as a critically endangered species [13]. Sea turtles have historically constituted an important food resource for indigenous communities and a tradition of meat production persists in the Cayman Islands, Réunion and the Ogasawara Islands of Japan [4]. However, overexploitation led to substantial declines in many sea turtle populations by the late 20th century [22,23]. Consequently, the CITES treaty (The Convention on International Trade in Endangered Species of Wild Fauna and Flora) prohibits international trade in turtle meat, restricting its consumption and sale to local populations and domestic markets [6]. Artificial rearing of several sea turtle species is conducted in

tropical regions, predominantly for conservation purposes [10]. The green sea turtle (*Chelonia mydas*) is farmed in the Cayman Islands, Suriname, Japan and Réunion Island [6,13], while hawksbill turtles (*Eretmochelys imbricata*) are also reared, although in a much smaller number globally [10]. Some of the edible turtle species are shown in Figure 3, Whereas global distribution of farm-raised and wild turtles is presented in Figure 4 [4].

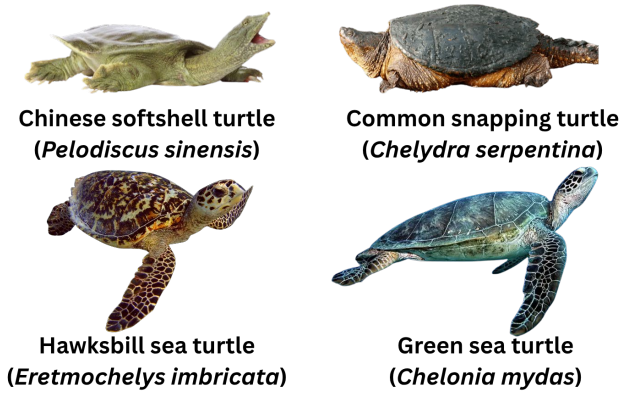

Figure 3. Edible turtle species (adapted from Domínguez et al. [4]).

Several squamate reptiles, including lizards and snakes, constitute important local food resources in various regions, and some species are regarded as gastronomic delicacies [13].

Figure 4. Global distribution of farm-raised and wild turtles (adapted from Domínguez et al. [4]).

Regarding lizards, three main groups are used for human consumption: tegus and iguanas in the Americas and monitor lizards in Africa and Asia [4]. In part of Central and South America and Asia, iguanas and snakes are commonly farmed for meat production, lizard farming, particularly of the omnivorous tegu (*Tupinambis* spp.), is especially prominent in Argentina, whereas the farming of monitor lizards is more frequent in Africa [4]. The most commonly consumed squamate species by humans are presented in Figure 5 [4].

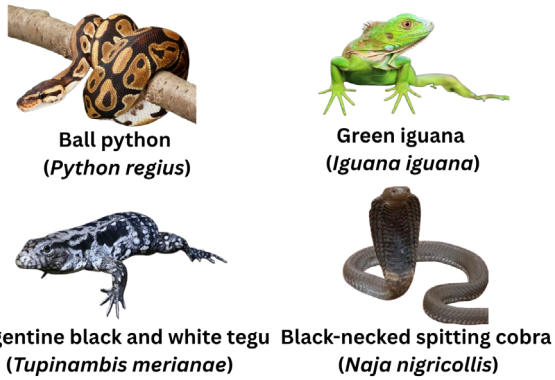

Figure 5. Edible snake and lizard species (adapted from Domínguez et al. [4]).

The global distribution of snakes, and lizards, is depicted in Figure 6 [4]. The primary objectives of snake farming are the production of skin and meat, as well as the extraction of venom [10]. Although skin production is generally the principal focus, snake meat is also harvested and is highly valued as a delicacy [6]. Reticulated pythons (*Python reticulatus*) and Burmese pythons (*Python molurus bivittatus*) are farmed extensively in several Asian countries [24]. In the US, various snake species, including pythons and rattlesnakes (*Crotalus* spp.), are raised for meat designated for human consumption in the US, Mexico, Brazil and parts of Europe [4].

Figure 6. Global distribution of wild and farm-raised snakes, iguanas and lizards (adapted from Domínguez et al. [4]).

In central Nepal, commercial snake farms produce venom, meat and skin for international markets, including Europe, Australia and other Asian countries [4]. In Africa, pythons (*Python sebae*), cobras (*Naja nigricollis*) and adders (*Causus rhombeatus* and *Bitis* spp.) are harvested and a part of this production enters trade [13].

Furthermore, the filesnake (*Acrochordus arafurae*) constitutes a traditional food source for Aboriginal Australians [4], while the boa constrictor (*Eunectes murinus*) and the bushmaster (*Lachesis muta*) are consumed in Brazil [11].

Iguanas have served as a food source for more than 7000 years in parts of Central and South America. Their diet consists predominantly of fruits, supplemented with leaves and flowers [6]. As with other reptiles, iguanas are primarily exploited for their meat and skin [12]. Iguana meat is consumed and traded in numerous Central and South American countries, including Panama, Costa Rica, Honduras, Guatemala, El Salvador, Nicaragua, Colombia, Venezuela, Peru, Paraguay and northern Argentina [12]. Habitat destruction and intensive hunting have led to severe declines and near-local extinction of iguana populations in some regions [4]. In response, several countries have established iguana farming initiatives aimed at both conservation and meat production for local communities, where iguana meat is often preferred over other animal proteins [6]. The green iguana (*Iguana iguana*) and the black iguana (*Ctenosaura* spp.) are the principal species farmed for human consumption [4].

Tegus (*Tupinambis* spp.) are large South American lizards widely distributed in regions with tropical to temperate climates, including southern Brazil, Argentina and Uruguay [25]. Traditionally, indigenous communities have hunted these lizards for their meat, fat and skin [25]. Although wild harvest for skins and meat continues, farming of tegus has been initiated in Argentina [4].

Monitor lizards (*Varanus* spp.) are distributed across Africa, Asia and Oceania. In contrast to tegus and iguanas, their carnivorous diet renders captive breeding considerably more challenging and less economically viable [4,6]. In West and Central Africa, Nile monitor lizards (*Varanus niloticus*) are harvested for bushmeat and part of this production enters trade [26]. The meat of the ocellated lizard (*Timon lepidus*), which inhabits southwestern Europe (Spain, Portugal, France and Italy), was historically consumed in the Iberian Peninsula [4]. However, deliberate capture, keeping, killing, trade and possession are now prohibited [10]. Additionally, certain lizard species continue to be traditionally consumed by Australian Aboriginal communities [6].

3. Nutritional composition of edible reptiles

Crocodile meat is a notable by-product of the leather industry with increasing economic significance [4]. It is also considered beneficial for human health due to its high content of unsaturated fatty acids, proteins, and minerals [7], and is already available in certain premium markets [27]. Proximate composition analyses of crocodile meat indicate protein content of 14.0–24.4% in Nile crocodile, 16–18% in American alligator and 19.4–24.4% in yacare caiman, values comparable to conventional meats and supporting crocodile meat as a substantial protein source [4]. Mean moisture content across species was 74.5%, with individual values ranging from 66.1% to 80.0%, while ash content was consistently low (0.42–1.0%) in all cases [28]. Lipid content exhibited greater variability: 0.47–13.3% in Nile crocodile, 0.8–1.0% in American alligator and 0.29–4.2% in yacare caiman [4]. Such variation may reflect multiple factors, notably anatomical location, since several studies report higher fat and lower moisture content in tail muscle compared to leg and neck muscles [28]. Crocodile fat is characterized by high proportions of monounsaturated (MUFA; 33.2–51.3%) and saturated fatty acids (SFA; 26.0–41.1%), whereas polyunsaturated fatty acids (PUFA) exhibit greater variability [28]. Reported PUFA contents are similar in American alligator and yacare caiman (17.6–19.6%), while values in Nile crocodile range from 10.7% to 38.1% [4,28]. From a nutritional perspective, crocodile meat is advantageous due to its substantial levels of essential fatty acids [4]. Linoleic acid (C18:2n-6) ranges from 8.4 to 10.9% in meat of American alligator and yacare caiman, and from 9.1 to 29.6% in meat of Nile crocodile, while α-linolenic acid (C18:3n-3) ranges from 1.4 to 3.3% [27]. In addition, crocodile meat contains appreciable amounts of long-chain fatty acids of high biological relevance, including n-6 derivatives such as arachidonic acid (C20:4n-6; ≈4.3%), and n-3 fatty acids in American alligator, particularly eicosapentaenoic acid (EPA, C20:5n-3; ≈1.7%) and docosahexaenoic acid (DHA, C22:6n-3; ≈5.6%) [27]. The n-6/n-3 ratio remains within internationally recommended limits (<4) in meat of American alligator and yacare caiman, whereas in meat of Nile crocodile it ranges between 5.35 and 9.02 [27]. Studies further indicate that

crocodile meat is rich in essential amino acids and minerals [4,27,28]. Amino acid composition data available for meat of Nile crocodile and American crocodile show glutamic acid as the predominant amino acid, followed by aspartic acid, lysine and leucine. Regarding mineral content of crocodile meat, potassium is the major mineral (242–367 mg/100 g), followed by phosphorus (194–231 mg/100 g). Sodium levels are low (28–47 mg/100 g), as are iron concentrations (0.3–0.9 mg/100 g) [4,27,28]. Collectively, these characteristics suggest that crocodile meat can be marketed as a healthy food, owing to its favourable unsaturated fatty acid profile, high protein content and appreciable levels of minerals and essential amino acids, supporting its suitability for human consumption [4,7]. The proximate composition, fatty acids, amino acids and minerals of the main edible crocodile species are displayed in Table 1.

Proximate composition data for turtle meat indicate protein contents ranging from 13.9% to 20.8% [4]. Mean moisture content is approximately 80%, with reported values between 65.9% and 83%. Ash content shows considerable variability among species. Fat content is generally low in snapping turtle (0.2%), hawksbill turtle (0.65–1.0%) and green sea turtle (0.4–1.0%). In contrast, Chinese soft-shelled turtle (1.2–10.6%) exhibits a wider range of fat contents, reaching up to about 10%. In Chinese soft-shelled turtle, reported fat levels range from 0.35% to 8.0%, whereas the other species typically show values close to 1% [4]. The available fatty acid data are limited and largely restricted to meat of Chinese soft-shelled turtle. In this species, MUFA constitute the predominant fraction (31–65%), followed by either PUFA (3.2–30.1%) or SFA (23.2–26.3%), depending on the source [4,31,32]. Essential fatty acids display pronounced variability: linoleic acid (C18:2n-6) content ranges from 2.9% to 26.8%, whereas α-linolenic acid (C18:3n-3) content from 0.3% to 3.3% [31]. Notably, Chinese soft-shelled turtle meat contains relatively high levels of long-chain n-3 fatty acids of recognized biological importance, including EPA (C20:5n-3; 1.7–6.6%) and DHA (C22:6n-3; 3.7–8.1%) [4]. The n-6/n-3 ratio in meat of Chinese soft-shelled turtle (0.73–1.54) falls well within internationally recommended values (<4) [32]. Information on amino acid composition is available only for meat of hawksbill turtle and green sea turtle [4,31,32]. Results, expressed as g/100 g of lyophilized turtle meat sample, indicate that lysine and leucine are the predominant amino acids, followed by isoleucine, valine, histidine and arginine, which occur at similar levels [4]. Data on the mineral composition of turtle meat are also scarce. Reported iron concentrations are relatively low, ranging from 1.3 to 2.5 mg/100 g [4]. Overall, apart from basic proximate composition, information on the detailed nutritional profile of turtle meat (fatty acids, amino acids and minerals) remains limited. Further research is required to comprehensively characterize its nutritional properties and to better assess the potential health implications of turtle meat consumption.

As for lizard meat, in Geen iguana and Tegu lizard protein contents range from 18.8 to 23.6 g/100 g of fresh meat, whereas in snakes protein levels range from 48 (in ball python) to 79.2 g/100 g of dry matter (in black-necked spitting cobra). Fresh iguana and Tegu lizard meat contains 72.0–77.2% moisture and 0.91–1.59 g ash/100 g fresh meat [4]. In meat of snakes, ash content ranges from 5.17 to 19.2 g/100 g of dry matter. Fat content in snake meat is relatively low, varying between 3.62% and 6.35% on a dry matter basis, while meat of iguana and Tegu lizard exhibits fat levels between 1.92% and 4.45%. In iguana and tegu lizard meat SFA constitutes the predominant class (23.8–36.9%), followed by MUFA (35.6–50.9%) and PUFA (15.8–28.5%). Linoleic acid (C18:2n-6) represents 5.2% of total fatty acids in iguana and 17.3–22.7% in Tegu lizard, while α-linolenic acid (C18:3n-3) accounts for 9.0% in iguana and 1.4% in Tegu lizard [4]. Long-chain n-3 PUFA, EPA (C20:5n-3) and DHA (C22:6n-3), are present only in trace amounts (0.02–0.6%) in lizard meat. The n-6/n-3 ratio in iguana meat (0.53) falls within international recommendations (<4), largely due to its relatively high C18:3n-3 content, whereas Tegu lizard meat displays markedly elevated ratios (15.3–17.2) [4]. The amino acid profile of black-necked spitting cobra meat is dominated by glutamic acid, followed by aspartic acid, with leucine, lysine, arginine and alanine occurring at comparable intermediate levels [4,33]. In contrast, iguana meat is characterized by a predominance of phenylalanine, followed by leucine, lysine and isoleucine. Mineral composition also varies among species. Iguana meat contains particularly high potassium (193.8–1323 mg/100 g), phosphorus (217 mg/100 g) and sodium (67.1–189.4 mg/100 g) levels [33].

Table 1. Proximate composition and nutritional characteristics of crocodile meat.

	Crocodylus niloticus [13]	*Crocodylus acutus* [4]	*Alligator mississippiensis* [29]	*Caiman yacare* [27,30]
Proximate composition	**g/100 g**	**n/a**	**g/100 g**	**g/100 g**
Moisture	66.1 – 75.9	-	73.0 – 80.0	75.2 – 77.1
Protein	14.0 – 22.9	-	16.0 – 18.0	19.4 – 22.4
Fat	0.47 – 13.3	-	0.8 – 1.0	0.58 – 1.0
Ash	0.42 – 0.97	-	0.5 – 1.0	0.58 – 1.0
Fatty Acids	**%**	**n/a**	**%**	**%**
C16:0	20.2 – 25.4	-	19.9 – 21.5	21.9
C16:1n-7	3.1 – 5.9	-	6.5 – 6.9	2.72
C18:0	7.9 – 9.9	-	4.4 – 4.8	15.4
C18:1n-9	27.3 – 43.1	-	40.9 – 44.4	34.9
C18:2n-6	9.1 – 29.6	-	9.1 – 10.5	8.4
C18:3n-3	1.6	-	1.4 – 1.5	3.32
C20:4n-6	4.2	-	-	4.34
C20:5n-3	0.20 – 0.48	-	1.6 – 1.8	0.76
C22:6n-3	0.90 – 1.1	-	5.4 – 5.8	0.57
Σ SFA	28.7 – 37.7	-	26.0 – 28.7	41.4
Σ MUFA	33.2 – 51.1	-	47.4 – 51.3	39.2
Σ PUFA	10.7 – 38.1	-	17.6 – 19.6	19.4
Σ n-6	9.1 – 34.3	-	9.2 – 10.6	12.9
Σ n-3	1.7 – 3.8	-	8.4 – 9.0	4.7
n-6/n-3	5.35 – 9.02	-	1.09 – 1.17	2.74
Amino Acids	**g/kg meat**	**g/100 g protein**	**n/a**	**n/a**
Lysine	6.97 – 13.8	9.84	-	-
Methionine	2.06 – 5.72	2.93	-	-
Leucine	6.43 – 12.6	8.87	-	-
Isoleucine	3.56 – 8.52	5.24	-	-
Phenylalanine	2.91 – 6.02	4.45	-	-
Valine	3.47 – 7.69	4.82	-	-
Histidine	2.15 – 5.75	2.99	-	-
Serine	2.82 – 6.08	3.31	-	-
Arginine	6.35 – 9.65	5.88	-	-
Cysteine	2.07 – 2.57	-	-	-
Tyrosine	2.60 – 5.89	5.44	-	-
Alanine	4.53 – 9.02	6.59	-	-
Aspartic acid	13.6 – 16.8	8.43	-	-
Glutamic acid	21.7 – 27.5	16.96	-	-
Glycine	4.06 – 10.7	5.64	-	-
Proline	5.31 – 6.48	-	-	-
Minerals	**mg/kg**	**n/a**	**mg/100 g**	**n/a**
Ca	68.0	-	9.0	-
Mg	185.0	-	27.0	-
P	1939.0	-	231.0	-
Na	282.0	-	47.0	-
K	2423.0	-	367.0	-
Fe	3.0	-	0.9	-

Abbreviations:
SFA - Saturated fatty acids; MUFA – Monounsaturated fatty acids; PUFA - Polyunsaturated Fatty Acids, Σ n−3 – total omega-3 fatty acids, n−6/n−3 – ratio of total omega-6 to total omega-3 fatty acids.

In meat of black-necked spitting cobra, phosphorus (161 mg/100 g) is the major mineral, followed by potassium (71.6 mg/100 g), with calcium (66.8 mg/100 g), sodium (63.5 mg/100 g) and magnesium (60.9 mg/100 g) present at similar concentrations. In *Phyton regius*, sodium is the predominant mineral (699 mg/100 g), followed by magnesium (480 mg/100 g), potassium (428 mg/100 g) and calcium (419 mg/100 g) [33]. Overall, these findings indicate that squamate meat is rich in high-quality protein, essential amino acids and minerals, while being relatively low in fat, supporting its suitability as a nutritious component of the human diet [4, 33]. Proximate composition, essential amino acids, saturated and unsaturated fatty acids of snake, swine, poultry and cattle meat are shown in Table 2 [1].

Consumer preference for products, as indicated by high sensory-evaluation scores, directly influences market demand [1]. While sensory-evaluation protocols are well established for meat of traditional livestock species, their application to exotic meats remains an emerging field. Recent consumer-based sensory studies of Anaconda (*Eunectes* spp.) meat illustrate this point. A consumer analysis found that participants generally "slightly liked" to "moderately liked" Anaconda meat, describing it as fibrous with an intense flavour. Respondents reported willingness to purchase and consume the meat at home and rated its colour and taste more favourably than those of other tested reptile species [1]. Complementary work reported that Anaconda meat possesses a striking, more intense taste and a more fibrous texture compared with chicken and pork [1]. Such pronounced flavour and texture characteristics may constrain acceptability to consumers who prefer bolder-tasting meats, relative to those accustomed to conventional livestock products [1].

Table 2. Comparison of proximate composition, essential amino acids and fatty acid profiles among snake, swine, poultry and cattle meat [1].

	Snake	*Swine*	*Poultry*	*Cattle*
Proximate composition		**(%)**		
Protein	14.8 - 18.5	20.1 - 25.6	19.9 – 23.9	19.1 - 22.3
Fat	0.3 - 6.4	2.3 - 4.5	1.3 - 1.4	1.7 - 9.8
Ash	1.0 - 5.3	1.2 - 1.5	1.0 - 4.9	1.1 - 1.3
Moisture	75.0 -85.0	70.4 - 76.5	74.1 - 76.3	72.3 - 76.1
Fatty Acids		**(%)**		
Σ SFA	29.4	38.7 - 42.3	30.4 - 32.2	35.2 - 41.4
Σ MUFA	15.5	46.8 - 49.2	27.8 - 37.4	45.7 - 49.3
Σ PUFA	46.9	10.6 - 32.5	31.5 - 38.2	2.9 - 5.3
Amino Acids		**(g amino acid / 100 g of protein)**		
Histidine	3.8	3.6 - 3.7	3.2 - 4.3	2.8 - 3.2
Isoleucine	4.3	3.9 - 4.0	3.6 - 5.2	4.1 - 5.0
Leucine	8.4	7.0 - 7.1	1.5 - 8.4	6.7 - 8.5
Lysine	9.4	7.6 - 7.8	7.7 - 7.9	7.2 - 8.2
Methionine	11.2	1.9 - 2.4	2.9 - 3.0	2.2 - 2.5
Phenylalanine	4.3	3.4 - 3.8	4.1 - 4.4	3.4 - 4.1
Threonine	4.6	4.0 - 4.1	4.2 - 4.7	3.7 - 4.2
Tryptophan	0.3	1.1 - 1.3	0.8 - 1.3	1.0 - 1.3
Valine	4.0	4.0 - 4.7	4.0 - 6.0	4.7 - 5.6

Abbreviations:
SFA - Saturated fatty acids; MUFA – Monounsaturated fatty acids; PUFA - Polyunsaturated Fatty Acids.

4. Safety Concerns and Reptile Meat

Biological hazards associated with reptile products arise from agents present in live animals (enteric bacteria, parasites, viruses and biotoxins) and from contamination during slaughter and processing [6].

Among bacteria, *Salmonella* spp. represents the major hazard [6]. High intestinal carriage rates (>50%) are well documented in captive and wild reptiles, including crocodilians, iguanas, turtles

and snakes [6]. Fresh and frozen crocodile meat frequently harbours diverse *Salmonella enterica* subspecies, including serotypes within subspecies *enterica* that are relevant for human disease (e.g. *Salmonella* Typhimurium, *Salmonella* Enteritidis) [6]. Outbreaks of human salmonellosis have been linked to soft-shelled terrapin meat and blood in Japan and to partially cooked green sea turtle meat in Northern Australia [6,34]. Additional cases have been associated with dried rattlesnake meat used as a folk remedy [6]. Other bacterial hazards include *Vibrio* sp. Surveys in China indicate that turtles/terrapins and their pond water are often contaminated with *Vibrio* spp., including *Vibrio cholerae*. Cholera toxin–producing *Vibrio mimicus* has been associated with outbreaks linked to the consumption of raw sea turtle eggs and has also been identified in soft-shelled terrapins in Japan [6]. By contrast, other bacterial genera occasionally isolated from reptiles (e.g. *Aeromonas*, *Mycobacterium* and *Chlamydia*) currently appear to pose minimal risk via meat consumption [6]. Fungal and viral infections are common in reptiles, but to date have not been implicated in foodborne transmission to humans [6]. Natural transmissible spongiform encephalopathies have not been reported in reptiles, and available data suggest a substantial species barrier to mammalian prions; current concern is limited to a theoretical risk of transient carriage after ingestion of contaminated feed [35].

In contrast, several metazoan parasites carried by reptiles constitute well-documented zoonotic hazards through meat consumption. Sparganosis, caused by plerocercoid larvae of *Spirometra* spp, is acquired predominantly by ingestion of raw or undercooked snake meat; very high infection prevalences and parasite burdens have been reported in snakes in East Asia [6]. Historical detection of *Spirometra erinacei* in crocodile meat prompted regulatory requirements for freezing crocodile meat (e.g. −12 °C for ≥5 days) to inactivate plerocercoids [6]. *Trichinella* spp. represent another key hazard. Non-encapsulated species *Trichinella papuae* and *Trichinella zimbabwensis* infect a range of reptiles (crocodiles, caimans, monitor lizards, pythons and turtles) and are transmissible to mammals, including primates [36,37]. Human trichinellosis outbreaks have been documented after consumption of monitor lizard and turtle meat in Thailand [36,37]. Consequently, some legislations (e.g. the EU and Australia) mandate *Trichinella* inspection of reptile meat and/or validated freezing or cooking regimes [6]. Additional parasitic hazards include gnathostomiasis and pentastomiasis [6]. *Gnathostoma* spp. larvae have been found in snakes and can cause severe cutaneous and visceral larva migrans, including neurologic disease, following ingestion of raw or lightly cooked snake meat [6]. Pentastomid ("tongue worm") larvae, particularly *Armillifer* spp, infect snakes and crocodilians and can be transmitted to humans through ingestion of infected tissues or eggs, leading to often asymptomatic but sometimes clinically significant visceral lesions [6].

A distinct category of risk is posed by marine biotoxins. Chelonitoxism, a severe food poisoning syndrome associated with consumption of sea turtle meat, is attributed mainly to lyngbyatoxins and possibly other toxins accumulated via ingestion of cyanobacteria such as *Lyngbya majuscula* [6]. Multiple outbreaks involving high case fatality rates have been reported in the Caribbean, Indian Ocean and Pacific regions, predominantly linked to hawksbill turtles and, less frequently, green sea turtles [38]. The toxins appear heat-stable, whereby all organs may be hazardous, with reports of secondary poisoning in breastfed infants [38].

Effective risk mitigation relies on a "farm-to-fork" approach incorporating Good Hygienic Practice, Good Manufacturing Practice and Hazard Analysis and Critical Control Points (HACCP), avoidance of risky feeding practices (e.g. unprocessed animal by-products and on-farm carcass recycling), and validated processing measures such as adequate cooking, targeted freezing regimes for specific parasites, and exclusion of toxic sea turtle species from the food chain [35].

5. Environmental impact of reptile farming

Compared with conventional livestock, reptile farming has a distinctive environmental profile because they are ectothermic, can be raised at relatively high stocking densities and are often integrated with wildlife management programs. However, the net environmental outcome is highly context-dependent and remains understudied in formal life-cycle terms [39].

A major potential advantage is resource efficiency. As ectotherms, reptiles do not expend energy on maintaining a constant body temperature, so a larger fraction of ingested energy can be converted into biomass [40]. This generally translates into lower feed requirements per unit of usable product compared with endothermic livestock such as cattle or pigs, especially under well-managed farming conditions [40]. When reptiles are fed on slaughterhouse offal, fish by-products or invasive species carcasses, farms can partially "upcycle" waste streams that would otherwise require disposal, potentially reducing overall pressure on agricultural land and feed crops [41]. In some cases, reptile farming is explicitly linked to sustainable use schemes that may confer indirect environmental benefits [41]. Crocodilian farming systems, in which eggs or juveniles are harvested from the wild under quotas and a proportion of animals or eggs are returned to the wild, have been used in several countries as an incentive for habitat protection and wetland conservation [42]. By assigning economic value to living populations and their habitats, such systems can reduce incentives for land conversion and uncontrolled hunting, although outcomes depend strongly on governance and enforcement [41]. Notwithstanding these potential benefits, several environmental risks remain a concern. Intensive reptile farms can generate localized pollution through nutrient-rich effluents, chemical residues (e.g. disinfectants) and solid waste (skins, carcasses and unused feed), which may affect surrounding soils and water bodies if waste management is inadequate [41]. High-density aquatic systems (e.g. turtle or crocodile farms) are especially prone to water quality degradation and pathogen accumulation, necessitating substantial water treatment and posing risks to nearby ecosystems when effluents are not properly treated [39]. The energy required for heating, pumping and maintaining controlled environments can also be significant, particularly in temperate regions, potentially offsetting some of the advantages derived from ectothermic physiology if energy is fossil-fuel based [39]. Reptile farming can interact with wild populations and ecosystems in additional ways. Escape or intentional release of farmed reptiles may lead to the establishment of non-native or genetically admixed populations, with associated impacts on native species and ecosystem function [39]. Where farms rely on wild-collected stock (eggs, juveniles or adults) unsustainable offtake can occur if management and monitoring are weak [43]. Conversely, when farming (or ranching) is effectively regulated and linked to legal trade frameworks such as CITES, it may reduce incentives for illegal hunting by providing legal products; however, empirical evidence is mixed and system-specific [42].

Overall, the environmental impact of reptile farming is highly heterogeneous and depends on species biology, production intensity, feed sources, energy mix, effluent management and governance context. Existing scientific literature emphasizes that reptiles can be relatively efficient converters of biomass and that well-designed farming systems may support habitat conservation, but also highlights pollution, disease and escape risks associated with poorly regulated intensive operations [39]. There is a clear need for rigorous, species and system-specific life-cycle assessments to quantify greenhouse-gas emissions, land and water use, pollution loads and to compare reptile farming more robustly with conventional livestock and aquaculture production.

6. Welfare and reptiles

Scientific understanding of reptile welfare has expanded markedly over the last decades, challenging the long-standing assumption that reptiles, as "primitive" or less expressive vertebrates, have minimal or poorly developed welfare needs. Contemporary work emphasizes that reptiles exhibit complex behavioural repertoires, learning abilities and stress physiology comparable in many respects to other vertebrates, and that they can experience pain, fear and distress [44,45,46]. As with mammals and birds, reptile welfare is now commonly conceptualized in multidimensional terms, covering physical health, behavioural opportunities, environmental quality and affective (emotional) states rather than survival alone [44]. Research on captive reptiles shows that suboptimal husbandry is frequently associated with chronic stress and pathology [44]. Inadequate thermal gradients, inappropriate humidity, poor diet and lack of environmental complexity have been linked to immunosuppression, stereotypic or abnormal behaviour, reproductive failure and increased

mortality [46]. Detailed ethological assessments indicate that reptiles use space non-randomly, interact with environmental features and modify activity patterns under stress, underscoring that welfare cannot be inferred from immobility or apparent "calm" alone [45]. These findings undermine the perception that reptiles are highly tolerant of confinement and highlight the need for species-specific environmental enrichment, appropriate substrates, shelters and opportunities for thermoregulation and behavioural choice [45]. Reptile farming, particularly of crocodiles, turtles and snakes, introduces specific welfare challenges due to high stocking densities, commercial pressures and the routine use of intensive systems. Studies of crocodile and turtle farms document frequent problems including skin and bite injuries, locomotor restriction, poor water quality, thermal and stocking-density stress, and high burdens of infectious disease and parasitism [47]. On some farms, reptiles are maintained in barren concrete pens or shallow ponds that preclude species-typical behaviours such as complex swimming, basking, burrowing or social spacing [47]. Assessment frameworks developed for captive reptiles generally conclude that standard industry practices often fail to meet minimum welfare criteria related to behavioural freedom and environmental control, even where growth and survival are adequate from a production standpoint [48]. Handling, transport and slaughter constitute additional critical points for welfare in farmed reptiles. Capture and restraint methods can induce significant physiological stress, while improper stunning or slaughtering techniques may prolong consciousness and nociception [48,47]. Although some producer and veterinary guidelines now recommend standardized procedures for handling, transport density, temperature management and slaughter of crocodilians and other farmed reptiles [47], empirical evaluations suggest inconsistent implementation and limited regulatory oversight in many producing countries [43]. Research on positive welfare states lags behind work on negative states, despite the consensus that absence of suffering does not equate to good welfare [49]. Overall welfare is better understood as a continuum, where positive experiences (e.g., exploration, play) and the reduction of negative states shape an individual's position [49].

Overall, the available scientific literature indicates that reptile welfare, both in general captivity and under farming conditions, has been historically neglected relative to mammals and birds, despite increasing evidence that reptiles have complex needs and can suffer significantly when those needs are not met. There is broad consensus that welfare assessments in reptile farms should move beyond simple production indicators (growth, survival) toward validated behavioural, physiological and clinical measures, and that species-specific husbandry standards, training and enforcement mechanisms are required to reduce welfare risks at scale [48,49].

7. Reptile meat and legislation

The sale and farming of reptiles are strictly regulated in many countries, primarily due to the conservation status and risk of extinction of numerous species [50]. Regulatory approaches to reptile meat trade are heterogeneous: in some legislations imports are prohibited, whereas in others they are allowed under specific conditions [50]. For example, Denmark has detailed rules for the import of reptile meat; crocodile meat must be frozen to inactivate parasites, particularly *Trichinella* spp, and subjected to examination for *Salmonella* spp. [35,50]. Reptile meat in the EU is regulated through horizontal food-safety and animal-health instruments rather than a single species-specific law. Microbiological criteria for reptile meat were introduced by Commission Regulation (EU) 2020/205 [51], which amends the microbiological-criteria Regulation (EC) No 2073/2005 [52] to add a *Salmonella* food-safety criterion for reptile meat. Official controls and border checks are regulated by Regulation (EU) 2017/625 (Official Controls Regulation) [53], which prescribes the performance of official controls, sampling, laboratory testing and the powers of competent authorities at Border Inspection Posts for consignments of animal origin products, including reptile meat. Regulation (EC) No. 2075/2005 [54] requires mandatory testing of reptile meat for *Trichinella* spp. using one of the methods approved by the European Commission (e.g. artificial digestion), based on a 10 g muscle sample. In crocodiles, recommended predilection sites are the *musculus masseter*, *musculus pterygoideus* and *musculus intercostales*, whereas in caimans and monitor

lizards the tongue and musculature of the fore and hind limbs are preferred [35].

In major producer countries, regulatory frameworks increasingly align reptile meat production with standards applied to meat of conventional livestock [50]. The Australian Meat Safety Act [55,56] specifies the conditions for establishing crocodile slaughterhouses, including requirements for facilities, equipment and surrounding infrastructure that closely mirror those for traditional abattoirs (e.g. toilets, dedicated rooms for veterinarians and official meat inspectors, cold-storage capacity), as well as detailed provisions on employee hygiene, staff qualifications and licensing conditions. Similarly, in Serbia reptile meat is subject to mandatory inspection for *Trichinella* larvae under the Rulebook on the Manner of performing official control of animals before and after slaughter for the presence of *Trichinella* in the meat [57]. Furthermore, reptile meat in Serbia must be tested for *Salmonella* spp. in accordance with the Rulebook on General and special conditions of food hygiene and microbiological criteria for food [58]. Collectively, these examples illustrate a trend towards the formal integration of reptile meat into existing food-safety systems through species-relevant, but largely livestock-analogous, regulatory requirements.

8. Conclusion

Reptile meat is a nutritionally promising alternative protein source, with many species, especially crocodiles and some turtles, showing high protein content, favourable fatty acid profiles (including long-chain n-3 PUFA) and relevant mineral levels, often comparable to or exceeding those of conventional livestock. These characteristics indicate that reptile meat can contribute to protein diversification, particularly in regions with an existing cultural tradition of reptile consumption. However, this review also highlights substantial risks and uncertainties. Important food safety hazards include high *Salmonella* burden, several zoonotic parasites (*Trichinella* spp. and *Spirometra* spp) and heat-stable biotoxins in sea turtles causing chelonitoxism. Environmentally, ectothermy and the use of low-value by-products can enhance resource efficiency, but poorly regulated systems may contribute to pollution, disease, escapes and unsustainable offtake from wild populations. Welfare concerns are significant, as current farming practices often fail to provide appropriate thermal, environmental and behavioural conditions or to ensure humane handling and slaughter. Overall, existing legislation shows that reptile meat is already incorporated into formal food safety systems in several countries. In the EU, mandatory testing for *Trichinella* spp. and *Salmonella* spp, with defined sampling protocols, explicitly addresses key reptile-specific hazards. Similar provisions in Australia Meat Safety Act and related food regulations, as well as Serbian rulebooks requiring *Trichinella* spp. and *Salmonella* spp. testing, demonstrating that crocodile and other reptile meats can be regulated under standards largely equivalent to those for conventional livestock. However, regulatory approaches remain uneven globally, indicating a need for further harmonization and clearer reptile-specific guidance.

Based on the available scientific literature, it can be concluded that reptile meat should not be regarded as a straightforward “sustainable” or “ethical” protein alternative. Its wider commercialization is very dependable on: (i) rigorous, species-specific food safety management; (ii) conservation-compatible, transparently managed sourcing and farming systems; (iii) development and enforcement of robust reptile-welfare standards and legislation; and (iv) closing key knowledge gaps in nutritional profiling, quantitative risk assessment and environmental life-cycle impacts.

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