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Research Article

Comparative Proximate Composition and Fatty Acid Profile of the Freshwater Apple Snail Pila Globosa During Active and Aestivation Periods

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Abstract

Pila globosa, a freshwater apple snail widely consumed in South and Southeast Asia, represents a promising alternative source of high-quality protein and essential fatty acids. However, limited information is available on how physiological dormancy (aestivation) influences its nutritional composition and lipid profile. This study compared the proximate composition and fatty acid profile of *P. globosa* during active and aestivation periods to evaluate the biochemical adaptations associated with dormancy and their nutritional implications. Proximate composition and fatty acid methyl ester (FAME) analyses were performed using standard analytical methods. During the active period, carbohydrate was the predominant component (40.55%), followed by protein (32.00%), ash (18.21%), moisture (6.40%), and fat (2.84%). In contrast, aestivation was characterized by a marked decline in carbohydrate content, accompanied by increases in protein, ash, moisture, and a nearly threefold increase in fat content (7.97%), indicating the utilization of carbohydrate reserves and metabolic adjustment during prolonged food deprivation. Fatty acid analysis revealed that polyunsaturated fatty acids (PUFA) constituted the major lipid fraction during the active period (40.51%), followed by monounsaturated fatty acids (MUFA, 29.36%) and saturated fatty acids (SFAs, 23.70%). Linoleic acid was the predominant PUFA, whereas oleic acid was the principal MUFA. During aestivation, the proportion of SFAs increased markedly, while MUFA and PUFA declined. PUFA declined from 40.51 to 15.55, resulting in a decrease in the PUFA/SFA ratio from 1.71 to 0.34 and in the n-6/n-3 ratio from 6.75 to 2.76. These findings demonstrate that *P. globosa* is a nutritionally valuable freshwater food resource rich in protein and essential fatty acids. Moreover, the pronounced biochemical alterations observed during aestivation reflect adaptive metabolic strategies for survival under adverse environmental conditions and highlight the importance of physiological state when evaluating the nutritional quality and optimal harvesting period of this species for human consumption.

Keywords

Pila Globosa, Proximate Composition, Fatty Acid Profile, Polyunsaturated Fatty Acids, Nutritional Value

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1. Introduction

The increasing global demand for sustainable and affordable sources of high-quality animal protein has stimulated considerable interest in alternative and non-conventional food resources with high nutritional value. Conventional livestock production is increasingly challenged by climate change, prolonged drought, rising feed costs, disease outbreaks, low productivity of indigenous animal breeds, and poor management practices. Consequently, alternative protein sources are being explored to improve food security and meet the growing nutritional demands of the global population. Sustainable utilization of aquatic food resources has also received increasing attention because of their relatively low environmental footprint and high nutritional value compared with conventional livestock production [1, 2]. Edible snails have emerged as promising alternative protein sources because of their excellent nutritional composition, environmental sustainability, and growing consumer acceptance [1, 3].

Snail meat is recognized as an important source of high-quality protein, essential amino acids, vitamins, minerals, and bioactive compounds, making it a valuable component of a balanced and healthy diet [1]. Fresh snail meat contains approximately 70% moisture and 60-70% protein on a dry-weight basis, while the shell is composed primarily of calcium carbonate, providing an additional source of dietary minerals [3]. Recent studies have further emphasized the nutritional and functional importance of edible freshwater gastropods as affordable protein sources capable of contributing to food security and human nutrition [2].

Among edible freshwater gastropods, *P. globosa* is an economically and nutritionally important apple snail widely distributed throughout Bangladesh and many Asian countries. The species is extensively utilized as human food, aquaculture feed, traditional medicine, and as a source of raw materials for poultry and aquaculture industries [5]. Previous studies have demonstrated that *P. globosa* contains biologically active proteins, a balanced composition of essential amino acids, fat-soluble vitamins, and important macro- and microelements, making it a promising alternative source of animal protein [6, 7]. A recent comprehensive review further highlighted the ecological, economic, nutritional, and ethnomedicinal importance of *P. globosa*, emphasizing its considerable potential as a sustainable freshwater food resource in South Asia [2].

The nutritional value of *P. globosa* is further enhanced by its fatty acid composition, particularly its polyunsaturated fatty acids (PUFA), including omega-3 (n-3) and omega-6 (n-6) fatty acids. These essential fatty acids play important physiological roles in maintaining cardiovascular health, regulating inflammatory responses, supporting retinal and brain development, and reducing the risk of several chronic diseases, including cardiovascular disorders, rheumatoid arthritis and certain cancers [7-9]. Long-chain n-3 PUFA such as eicosapentaenoic acid (EPA; C20: 5n-3) and docosahexaenoic acid (DHA; C22: 6n-3) are especially recognized for their beneficial effects on cognitive function, neurological development, and healthy ageing [7-9]. Consequently, characterization of the fatty acid composition of edible aquatic organisms has become an important criterion for evaluating their nutritional quality and health-promoting potential.

Like many freshwater gastropods, *P. globosa* undergoes aestivation, a physiological dormancy induced by adverse environmental conditions such as elevated temperature, reduced rainfall, dehydration, and food scarcity [4]. During this period, metabolic activity is markedly suppressed, allowing the organism to survive prolonged unfavorable conditions through coordinated physiological and biochemical adaptations. These adaptations include reduced energy expenditure, depletion of carbohydrate reserves, alterations in lipid metabolism, suppression of respiratory metabolism, modulation of antioxidant defense systems, and conservation of protein [4, 10]. Recent studies have demonstrated that aestivation in *Pila* species is accompanied by significant changes in carbohydrate metabolism, enzyme activities, oxidative stress responses, and lipid utilization, all of which contribute to survival under prolonged environmental stress [10]. These metabolic adjustments are expected to influence the nutritional composition of edible tissues and consequently affect their value for human consumption.

Although several studies have described the general nutritional composition and health benefits of *P. globosa* and other edible freshwater snails [5-7], comparative information regarding changes in proximate composition and fatty acid profiles during active and aestivation periods remains extremely limited. Most available studies have focused primarily on ecological, physiological, or biochemical responses to environmental stress rather than evaluating changes in nutritional quality associated with physiological dormancy [2, 10]. Consequently, little is known about how aestivation influences the relative abundance of saturated fatty acids (SFAs), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), and nutritionally important lipid quality indices in *P. globosa*. Understanding these biochemical changes is essential for elucidating metabolic adaptations during aestivation, determining the optimal harvesting season, and maximizing the nutritional value of this species for human consumption.

Therefore, the present study aimed to (i) compare the proximate composition of *Pila globosa* during active and aestivation periods, (ii) characterize changes in fatty acid composition associated with physiological dormancy, and (iii) evaluate the nutritional implications of these biochemical alterations for human nutrition. The findings provide new insights into the metabolic adaptations of *P. globosa* during aestivation and support its potential as an affordable, sustainable, and nutritionally valuable alternative source of high-quality animal protein and essential fatty acids.

2. Material and Method

2.1. Study Area

Freshwater apple snails (*Pila globosa*) were collected during the active period in September 2024 from Chalan Beel, located in Chaugram Union, Singra Upazila, Natore District, Rajshahi Division, northwestern Bangladesh (24°29′56.10″ N, 89°11′00.27″ E) (Figure 1). Chalan Beel is the largest freshwater wetland ecosystem in Bangladesh and provides a favorable habitat for diverse aquatic flora and fauna, including abundant populations of *P. globosa*. The study area is characterized by predominantly flat alluvial plains and falls within the western climatic zone of Bangladesh, which receives an average annual rainfall of less than 150 cm and experiences relatively low humidity (below 50%) [11]. The favorable ecological conditions and high abundance of freshwater mollusks make Chalan Beel an appropriate location for investigating the nutritional composition of *P. globosa*.

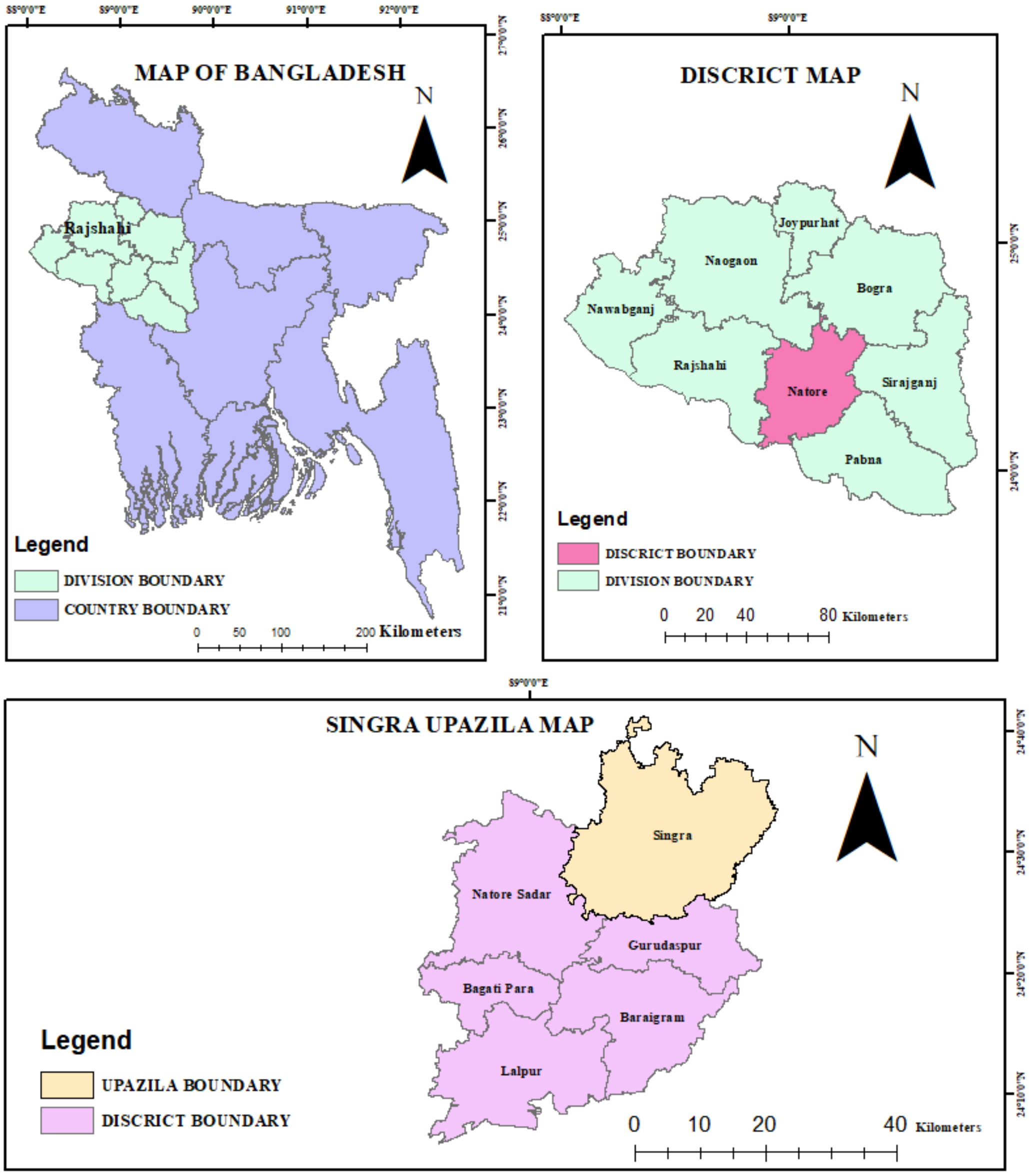

Figure 1. *The map illustrates the study area, Singra Upazila, Natore District, Rajshahi Division, Bangladesh (24°29'56.10'' N, 89°11'00.27'' E).*

2.2. Sample Collection

A total of 356 healthy freshwater apple snails (*Pila globosa*) were collected from Chalan Beel, Natore District, Bangladesh, during the active season in September 2024 with the assistance of local fishermen using traditional fishing nets and manual hand collection (Figure 2). During this period, the average ambient temperature was 30.5 ℃, relative humidity was

86%, and total rainfall was 477 mm. Immediately after collection, the snails were transported to the Institute of Environmental Science (IES) Garden, University of Rajshahi, Bangladesh, for experimental processing.

Figure 2. Natural view of the Chalan Beel wetland study area at Singra Upazila, showing typical habitat of P. globosa.

The collected snails were randomly divided into two equal groups (n = 178 each). The first group was processed immediately to represent the active period analysis while the other group (n = 178) was used for aestivation-period analysis. Prior to analysis, the snails were thoroughly washed with clean water to remove adhering mud and debris. The edible soft tissues were then carefully removed from the shells and used for proximate composition and fatty acid analyses. The total fresh body weight of this group was 4.81 kg. The sex ratio data were not provided because they do not influence the study results.

The second group (n = 178) was designated for the aestivation experiment. Before the onset of aestivation, the combined fresh body weight of these snails was 4.50 kg. On 29 September 2024, the snails were transferred to the Institute of Environmental Science (IES) Garden and individually buried in moist natural soil at a depth of approximately 3 cm, maintaining an inter-individual spacing of approximately 6 cm to minimize disturbance and facilitate natural aestivation behavior. The snails were allowed to aestivate under ambient environmental conditions for approximately four months. During this period, the average ambient temperature was 20.6 ℃, relative humidity was 76%, and total rainfall was 9 mm. At the end of the aestivation period (1 February 2025), the snails were carefully excavated from the soil and processed immediately for subsequent proximate composition and fatty acid analyses.

2.3. Sample Preparation

The collected snails were thoroughly washed under running tap water to remove adhering soil, mud, and other extraneous materials. The soft tissues were carefully separated from the shells, and the edible flesh was cut into small pieces before being dried in a hot-air oven at 70 ℃ for approximately 75 h until a constant weight was achieved. The dried samples were then ground into a fine powder using an electric blender and stored in airtight containers at 4 ℃ until further analysis of proximate composition and fatty acid composition (Figure 3).

Figure 3. (A), Flesh of Pila globosa after removal of the shell; (B), P. globosa flesh during oven drying; Oven-dried flesh powder of P. globosa.

2.3.1. Proximate Analysis

Proximate composition analysis was carried out at the Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka, Bangladesh. Moisture content was determined using an automatic moisture analyzer (RADWAG

MAC 50/NH, Germany). Crude protein content was determined by the micro-Kjeldahl method based on total nitrogen determination, and the protein content was calculated using the appropriate nitrogen-to-protein conversion factor. Crude fat content was determined using the Soxhlet extraction method. Ash content was determined according to the standard procedures of the Association of Official Analytical Chemists (AOAC, 1990) [12]. Carbohydrate content was calculated by difference using the following equation:

$$\text{Carbohydrate (\%)} = 100 - [\text{Moisture (\%)} + \text{Protein (\%)} + \text{Fat (\%)} + \text{Ash (\%)}]$$

All proximate composition results are expressed as percentages on a dry weight basis.

2.3.2. Fatty Acids Analysis

Total lipids were extracted from the dried snail powder using the chloroform: methanol (2:1, v/v) method containing 0.1 mg butylated hydroxytoluene (BHT) per 100 g solvent as an antioxidant, following the procedure described by Folch et al. [13]. Fatty acid methyl esters (FAMEs) were subsequently prepared from the extracted lipids according to the method described by Metcalfe et al., 1996 [14]. The FAMEs were analyzed using a Shimadzu GC-2010 gas chromatograph (Shimadzu Corporation, Kyoto, Japan) equipped with a flame ionization detector (FID) and a highly polar SP™-2560 fused-silica capillary column (75 m × 0.18 mm i.d., 0.14 µm film thickness; Supelco, USA). The oven temperature was initially maintained at 180 ℃ for 45 min, increased at a rate of 4 ℃ min^{-1} to 240 ℃, and held at 240 ℃ for 15 min. Nitrogen was used as the carrier gas at a constant flow rate of 1.0 mL min^{-1}. The injector and detector temperatures were both maintained at 250 ℃. Individual fatty acids were identified by comparing their retention times with those of authenticated FAME standards and were quantified as the relative percentage (%) of the total identified fatty acids. Since the data were machine-analyzed, the readings obtained did not require further statistical analysis; therefore, no statistical information has been provided.

3. Result

3.1. Proximate Composition of *P. globosa* During the Active Period

The proximate composition of *P. globosa* flesh during the active period is presented in Figure 4. The analysis revealed considerable variation among the measured nutritional components, including moisture, ash, crude protein, crude fat, and carbohydrate. Carbohydrate was the predominant constituent, accounting for 40.55% of the dry weight, followed by crude protein (32.00%), ash (18.21%), moisture (6.40%), and crude fat (2.84%).

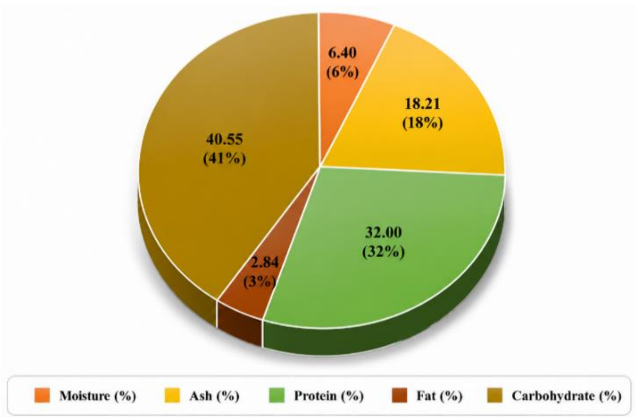

Figure 4. *Proximate composition (%, dry weight basis) of P. globosa flesh during the active period.*

3.2. Changes in Proximate Composition During Aestivation

A comparison of the proximate composition of *P. globosa* between the active and aestivation periods is presented in Figure 5. Distinct changes were observed in all measured nutritional components, reflecting the profound metabolic adjustments that occur during prolonged dormancy. The crude protein content increased slightly from 32.00% during the active period to 33.87% during aestivation. A marked increase in crude fat content was observed during aestivation, rising from 2.84% in the active period to 7.97%. Carbohydrate content exhibited the most pronounced decline during aestivation, decreasing from 40.55% during the active period to 24.75%. Ash content increased from 18.21% during the active period to 26.04% during aestivation. Moisture content increased only slightly from 6.40% during the active period to 7.37% during aestivation.

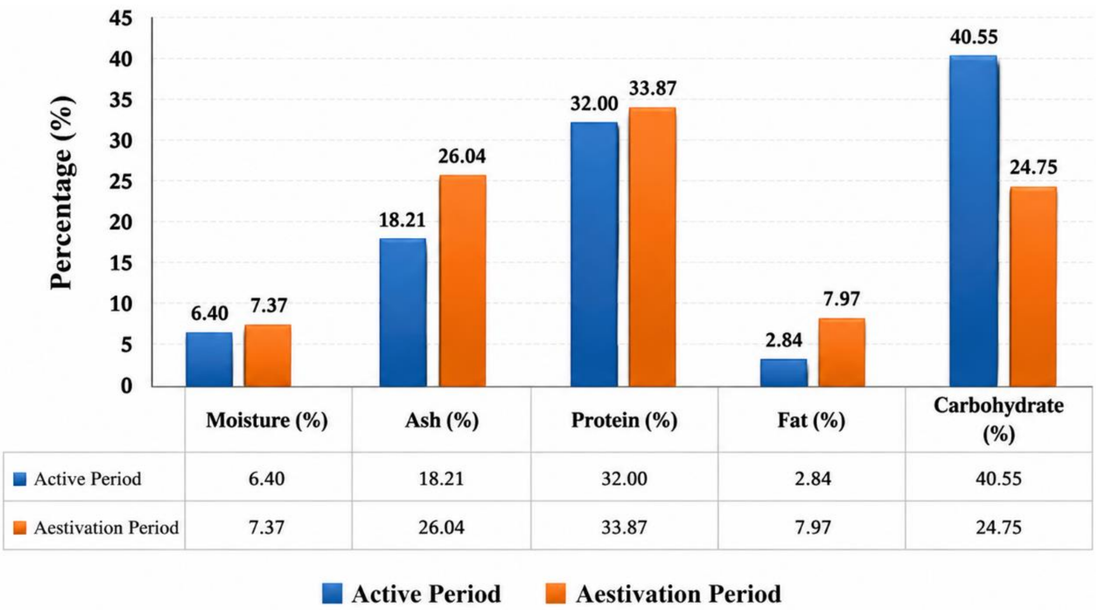

Figure 5. *Comparison of proximate composition of P. globosa flesh (%, dry weight basis) during active and aestivation periods.*

3.3. Fatty Acid Composition of *P. globosa* During the Active Period

The fatty acid composition of *Pila globosa* flesh during the active period is presented in Table 1. A total of seventeen fatty acids were identified, comprising seven saturated fatty acids (SFAs), four monounsaturated fatty acids (MUFA), and six polyunsaturated fatty acids (PUFA). Among these, PUFA constituted the predominant lipid fraction (40.51%), followed by MUFA (29.36%) and SFAs (23.70%), while unidentified components accounted for 5.74% of the total fatty acids. Within the saturated fatty acids, palmitic acid (C16:0) was the most abundant constituent (14.61%), followed by stearic acid (C18:0; 6.21%), whereas myristic, pentadecanoic, margaric, arachidic, and behenic acids were present in comparatively small amounts. Among the MUFA, oleic acid (C18:1, ω-9) was the dominant fatty acid (23.41%), with smaller contributions from eicosenoic acid (4.49%), vaccenic acid (0.76%), and palmitoleic acid (0.70%). In the PUFA fraction, linoleic acid (C18:2, ω-6) represented the major component (34.01%), followed by eicosatrienoic acid (2.78%), α-linolenic acid (2.02%), eicosadienoic acid (1.07%), docosadienoic acid (0.34%), and eicosapentaenoic acid (EPA; 0.29%).

Table 1. *Fatty Acids Composition of P. globosa's Lipid.*

Type of Fatty Acid	Name of Fatty Acid	C: D (Omega)	%
Saturated Fatty Acids (SFAs)	Myristic acid	C14:0	0.77
	Pentadecanoic acid	C15:0	0.62
	Palmitic acid	C16:0	14.61
	Margaric acid	C17:0	0.55
	Stearic acid	C18:0	6.21
	Arachidic acid	C20:0	0.56
	Behenic acid	C22:0	0.38
	Total SFAs		23.70
Monounsaturated Fatty Acids (MUFA)	Palmitoleic acid	C16:1 (Ω-7)	0.70
	Oleic acid	C18:1 c9 (Ω-9)	23.41
	Vaccenic acid	C18:1 c11 (Ω-7)	0.76
	Eicosenoic acid	C20:1 (Ω-9)	4.49

Type of Fatty Acid	Name of Fatty Acid	C: D (Omega)	%
	Total MUFA		29.36
Polyunsaturated Fatty Acids (PUFA)	Linoleic acid	C18:2 (Ω-6)	34.01
	Linolenic acid	C18:3 (Ω-3)	2.02
	Eicosadienic acid	C20:2 (Ω-6)	1.07
	Eicosatrienic acid	C20:3 (Ω-3)	2.78
	Eicosapentaenoic acid (EPA)	C20:5 (Ω-3)	0.29
	Docosadienic acid	C22:2	0.34
	Total PUFA		40.51
—	Unknown	—	5.74

3.4. Seasonal Changes in Fatty Acid Composition During Aestivation

The fatty acid profile of *P. globosa* changed markedly during aestivation Figures 6 and 7, indicating substantial metabolic adjustments associated with prolonged dormancy. Compared with the active period, the proportion of SFAs increased from 23.70% to 43.1%, whereas MUFA decreased from 29.36% to 20.36% and PUFA declined from 40.51% to 15.55%. Consequently, the PUFA/SFA ratio decreased from 1.71 to 0.34, while the n-6/n-3 ratio decreased from 6.75 to 2.76, demonstrating considerable remodeling of lipid composition during aestivation.

In contrast, the total MUFA content declined by approximately one-third during aestivation, largely because of reductions in oleic acid and eicosenoic acid. The most pronounced seasonal alteration occurred in the PUFA fraction. Total PUFA decreased from 40.51% during the active period to 15.03% during aestivation, representing a reduction of approximately 25 percentage points, with linoleic acid exhibiting the greatest decline.

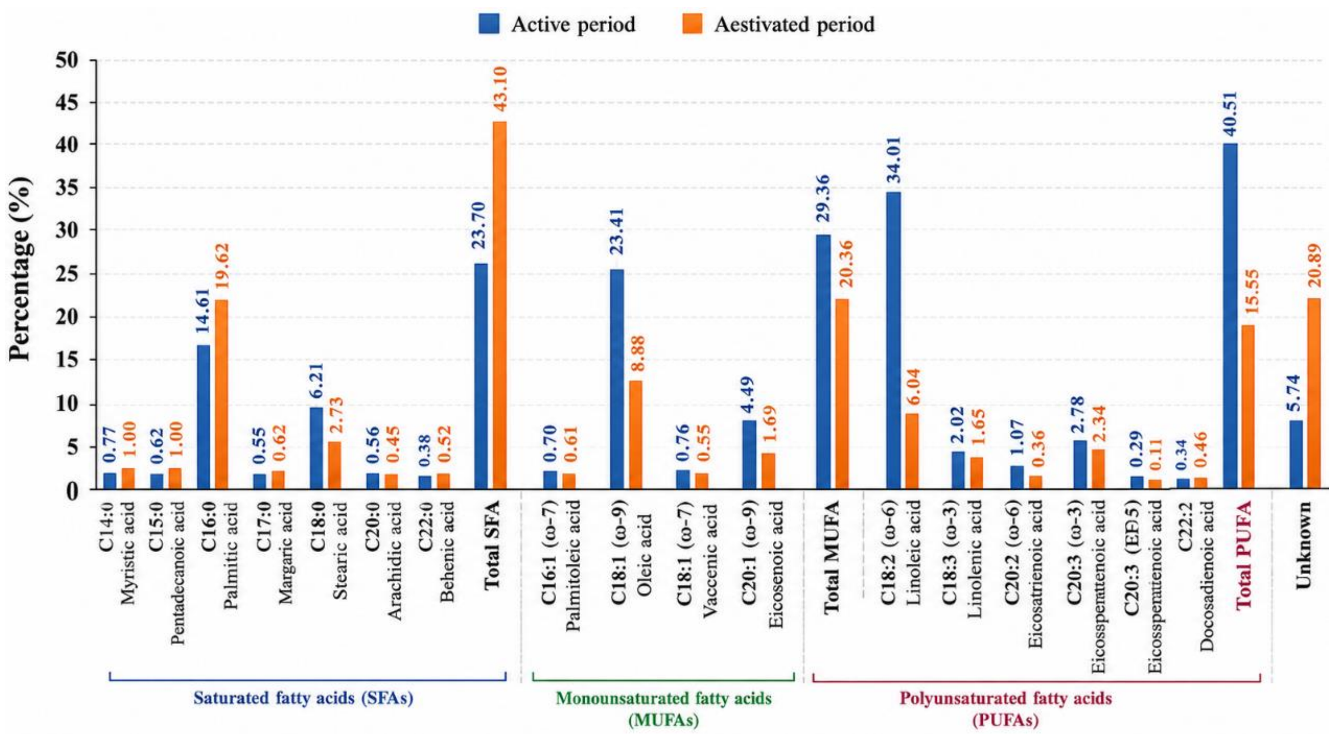

Figure 6. *Comparison of saturated (SFAs), monounsaturated (MUFA), and polyunsaturated (PUFA) fatty acid content (%) of P. globosa flesh during active and aestivation periods.*

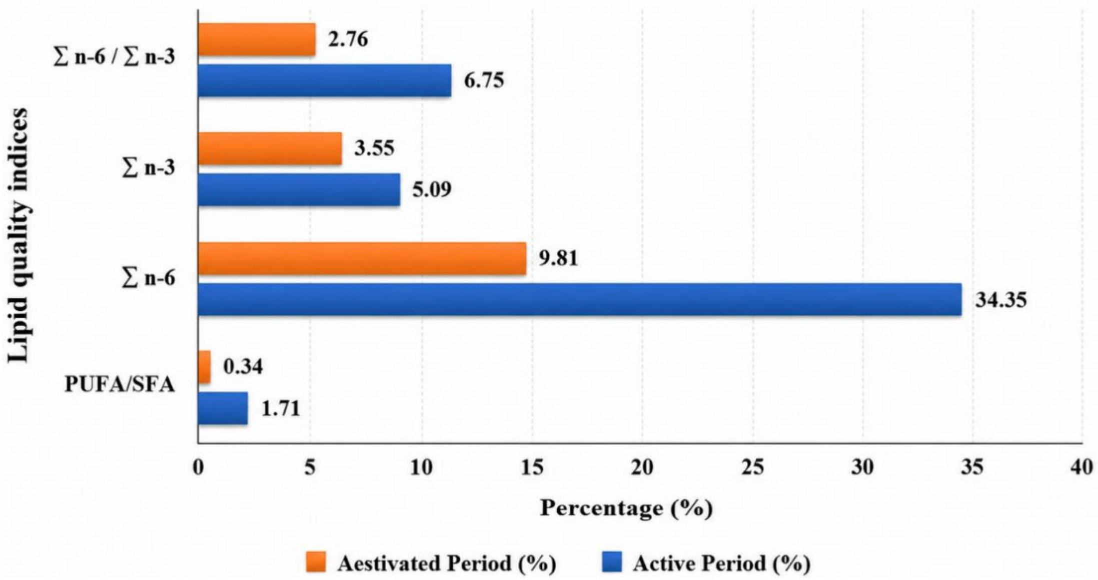

Figure 7. *PUFA/SFA and n-6/n-3 fatty acid ratios of P. globosa flesh during active and aestivation periods.*

3.5. Nutritional Contribution and Dietary Significance of Pila Globosa Flesh

As shown in Table 2, *P. globosa* contained 32.00 g protein per 100 g dry weight during the active period. Based on these recommendations, consumption of 100 g (dry weight) of *P. globosa* could provide approximately 64.3% of the daily protein requirement of a healthy adult weighing approximately 60 kg. Carbohydrates constituted the largest proximate component (40.55 g/100 g dry weight) during the active period. According to the Dietary Reference Intake (DRI), the Recommended Dietary Allowance (RDA) for protein is 0.8 g kg^{-1} body weight day^{-1}, equivalent to approximately 46 g day^{-1} for adult women and 56 g day^{-1} for adult men. In addition, there are only 2.84 grams of fat per 100 grams of food, which means that the food can be categorized as low in fat content.

Table 2. *Nutritional Contribution of P. globosa Flesh (Dry Weight Basis) to the Dietary Reference Intakes (Dris) of Healthy Adults.*

Name of Nutrient	Existing value (per 100g dry weight basis)	DRI/RDA*	Percentage (%) of DRI/RDA Supplied
Protein	32.00g	49.8 g/day (Adults, 60 kg body weight)	64.3%
Carbohydrate	40.55g	130 g/day (Adults)	31.2%
Fat	2.84g	Not established	Low-fat source

*RDA = Recommended Dietary Allowance; DRI = Dietary Reference Intake

4. Discussion

High temperature triggers aestivation in snails. As temperatures rise, they lower their metabolic rate to cope with heat and dehydration. This study demonstrates that *P. globosa* is a carbohydrate- and protein-rich freshwater gastropod with relatively low lipid content, highlighting its potential as a nutritious food resource. The proximate composition observed in the present study differs somewhat from previously reported values for *P. globosa*, in which protein, lipid, moisture, and ash contents were reported as 42.88%, 4.70%, 11.98%, and 14.17%, respectively [15]. Such variations are expected because the nutritional composition of freshwater mollusks is influenced by several factors, including habitat, seasonal changes, food availability, physiological condition, reproductive stage, and environmental characteristics. Nevertheless, the consistently high protein and moderate carbohydrate contents reported across studies confirm the nutritional importance of *P. globosa* as an alternative source of animal-derived nutrients.

Although proteins can serve as an auxiliary energy source during prolonged starvation, previous studies have suggested that they contribute approximately 32% of the energy requirements during dormancy in certain aestivating amphibians [16]. The relatively small increase observed in the present study indicates that protein reserves were largely conserved throughout aestivation, thereby preserving tissue integrity while minimizing excessive protein catabolism. Similar protein contents have been reported previously for *P. globosa*, with values of 33.81% during the active period [17]. Higher protein concentrations have also been reported for *P. globosa* (42.88% during the active period and 40.87% during aestivation) [7], whereas considerably lower protein contents have been recorded for the terrestrial snails *Archachatina marginata* and *Achatina achatina* (19.53% and 17.20%, respectively) [18] and for *Helix pomatia* (18%) [19]. These differences are most likely attributable to interspecific variation, environmental conditions, diet, and analytical methodology.

The consistently high protein content observed in *P. globosa* highlights its nutritional value as an affordable source of high-quality animal protein. Protein is indispensable for tissue growth, repair, enzyme synthesis, immune function, and numerous physiological processes in humans [20]. Consequently, freshwater snails such as *P. globosa* could contribute to improving dietary protein intake, particularly in regions where access to conventional animal protein sources is limited. As global demand for sustainable protein continues to increase, freshwater mollusks represent an underutilized resource capable of contributing to food security and nutritional diversification [21].

Rather than indicating active lipid accumulation during dormancy, this increase is more likely attributable to the preferential utilization of carbohydrate reserves during prolonged fasting, resulting in a relative enrichment of lipids in the remaining tissue. Similar physiological responses have been described in other mollusks undergoing metabolic depression, where carbohydrate reserves are consumed before substantial lipid mobilization occurs. Lipids also play essential roles in maintaining membrane integrity, cellular homeostasis, and long-term energy storage during periods of environmental stress. Interestingly, this trend contrasts with a previous study on *P. globosa*, which reported lipid contents of 4.70% and 3.10% during the active and aestivation periods, respectively [7]. Such discrepancies may reflect differences in environmental conditions, sampling season, food availability, or physiological status. Comparable lipid contents have been reported for other aquatic species, including *Scylla olivacea* (7.65%) and *Podophthalmus vigil* (5.09%) [22].

This substantial reduction strongly suggests that carbohydrates constitute the principal energy reserve utilized during dormancy. Glycogen and other stored carbohydrates are generally metabolized preferentially during periods of food deprivation to sustain essential physiological functions while minimizing the degradation of proteins and structural lipids. During the active period, the relatively high carbohydrate content supports energy-demanding activities such as locomotion, feeding, growth, and reproduction. In contrast, during aestivation, depletion of carbohydrate reserves reflects their continuous utilization to maintain basal metabolism under prolonged fasting conditions [23]. Previous studies have reported substantially lower carbohydrate contents for *P. globosa*, ranging from 0.42% [24] to 7.57% [25]. These large differences are likely associated with variations in species, habitat, environmental conditions, nutritional status, reproductive cycle, and analytical procedures. Increased carbohydrate accumulation before dormancy has also been attributed to enhanced feeding activity and energy storage in preparation for unfavorable environmental conditions [26]. This increase most likely reflects a relative concentration of mineral constituents following the depletion of organic components, rather than an actual accumulation of minerals during dormancy. Reduced feeding activity, metabolic depression, and the utilization of organic reserves collectively contribute to this proportional increase in ash content. Previous investigations reported considerably lower ash contents for *P. globosa* during the active period, including 1.31% [27] and 3.82% [26], whereas values of 7.83% and 12.91% have been reported for *Pila sanguinolentus* and *Cardisoma carnifex*, respectively [22, 28]. Consistent with the present findings, Shathi *et al*. [7] also observed a higher ash content during aestivation than during the active period.

Moisture is an essential physiological component involved in maintaining osmotic balance, transporting nutrients, and supporting metabolic reactions [29]. The relatively small variation observed in the present study suggests that *P. globosa* effectively regulates tissue water content during aestivation despite prolonged food deprivation and metabolic suppression. Previous studies have reported substantially higher moisture contents on a fresh-weight basis, including 85.5% for *P. globosa* and 66.17% for edible whelks [30]. These apparent differences primarily arise from the different expression bases (fresh weight versus dry weight) employed in the respective studies.

Collectively, the observed changes in proximate composition demonstrate that *P. globosa* undergoes significant metabolic reorganization during aestivation. Carbohydrates are preferentially utilized as the primary energy source, while proteins are largely conserved and lipids remain relatively preserved, representing an adaptive physiological strategy that enhances survival during prolonged periods of environmental stress and food scarcity.

In this study, the fatty acid distribution indicates that *P. globosa* possesses a lipid profile dominated by nutritionally beneficial unsaturated fatty acids, particularly polyunsaturated fatty acids, which are recognized for their important physiological and health-promoting functions. The predominance of linoleic acid and oleic acid demonstrates that the lipid fraction of *P. globosa* contains considerable quantities of nutritionally desirable unsaturated fatty acids. Fatty acids are indispensable structural and functional components of biological systems, serving as major constituents of cellular membranes, precursors of eicosanoids, and important energy substrates during metabolism [31]. Polyunsaturated fatty acids, particularly omega-3 and omega-6 fatty acids, are widely recognized for their beneficial effects on cardiovascular health, neurological development, immune regulation, and inflammatory responses [32]. Consequently, the predominance of PUFA observed in *P. globosa* suggests that this freshwater snail may represent a valuable dietary source of essential fatty acids for human nutrition. The marked increase in saturated fatty acids is primarily attributable to elevated proportions of palmitic acid (C16:0) and myristic acid (C14:0) during the dormant phase. Similar increases in saturated fatty acids have been reported in several molluscan species undergoing metabolic depression [34]. During aestivation, feeding ceases and metabolic activity is substantially reduced; consequently, stored carbohydrates become depleted and lipid metabolism is reorganized to maintain essential physiological functions. Saturated fatty acids exhibit greater resistance to oxidative degradation than unsaturated fatty acids and therefore become relatively enriched during prolonged dormancy. In addition, they provide a stable energy reserve that supports basal metabolism throughout extended periods of environmental stress [35]. Similar seasonal changes have been reported in edible snails and other mollusks inhabiting temperate environments [19, 33].

Oleic acid remained the predominant MUFA during both physiological stages, although its concentration decreased considerably after aestivation. MUFA play important roles in maintaining membrane fluidity, regulating lipid metabolism, and serving as readily mobilizable energy reserves. From a nutritional perspective, diets enriched in oleic acid have been associated with improved lipid profiles and reduced cardiovascular risk [36]. The reduction in MUFA observed in the present study therefore most likely reflects their preferential utilization as metabolic substrates during prolonged fasting rather than a decline in their nutritional significance. Similarly, the concentration of eicosenoic acid (C20:1, ω-9) decreased from 4.49% during the active period to 0.82% during aestivation, further supporting enhanced utilization of monounsaturated lipids during metabolic depression.

Comparable depletion of unsaturated fatty acids during dormancy has previously been reported in the giant African snail *Achatina achatina*, where free fatty acids were mobilized to sustain energy production when carbohydrate reserves became exhausted [37]. Similar reductions in PUFA during aestivation have also been documented for *P. globosa* [7]. Because polyunsaturated fatty acids contain multiple double bonds, they are more susceptible to oxidation and are preferentially utilized during prolonged periods of metabolic stress. Their depletion therefore reflects adaptive biochemical responses that facilitate survival under conditions of prolonged food deprivation.

Despite this reduction, the detected PUFA including linoleic acid (LA), α-linolenic acid (ALA), eicosatrienoic acid, eicosadienoic acid, and EPA remain nutritionally important because they serve as precursors of numerous bioactive lipid mediators involved in immune regulation, neural development, cardiovascular protection, and inflammatory homeostasis [38]. The predominance of linoleic acid during the active period further emphasizes the nutritional value of *P. globosa* as a source of essential fatty acids.

The PUFA/SFA ratio is widely regarded as an important indicator of lipid nutritional quality. Higher values generally reflect healthier lipid profiles because greater proportions of polyunsaturated fatty acids are associated with reduced cardiovascular risk. In the present study, the PUFA/SFA ratio declined from 1.71 during the active period to 0.34 during aestivation, indicating a substantial reduction in the nutritional quality of lipids following prolonged dormancy. Likewise, the n-6/n-3 ratio decreased from 6.75 to 2.76. Although no universally accepted optimal dietary ratio has been established, FAO and WHO expert consultations emphasize achieving adequate intakes of both omega-6 and omega-3 fatty acids rather than maintaining a fixed ratio [39]. The ratios observed in this study fall within the range previously reported for several terrestrial gastropods, including *Helix pomatia* and other edible snail species [40, 41], suggesting that ecological conditions, dietary resources, seasonal variation, and environmental temperature substantially influence fatty acid composition in freshwater mollusks.

Overall, the observed changes demonstrate that aestivation profoundly modifies lipid metabolism in *P. globosa*. The increase in saturated fatty acids, together with reductions in mono- and polyunsaturated fatty acids, reflects metabolic adaptation to prolonged dormancy through selective mobilization of unsaturated fatty acids while maintaining more stable saturated lipid reserves. These biochemical adjustments enable the organism to survive unfavorable environmental conditions but simultaneously reduce the nutritional quality of the edible flesh compared with the active period.

The nutritional composition of *P. globosa* indicates that this freshwater snail is a promising alternative animal-source food with the potential to improve food and nutritional security, particularly in low- and middle-income countries where access to conventional animal protein is often limited [2, 42]. The combination of a high protein content, moderate carbohydrate level, low fat content, and a favorable fatty acid profile highlights its value as an affordable nutrient-rich food resource. Considering the recommended carbohydrate intake of 130 g day^{-1} for healthy adults [42], 100 g (dry weight) of *P. globosa* can provide approximately 31.2% of the daily carbohydrate requirement. This relatively high carbohydrate content may serve as an important source of metabolic energy, particularly in communities where dietary energy intake is inadequate [43]. In contrast, the lipid content of *P. globosa* was relatively low (2.84 g/100 g dry weight), indicating that the species can be considered a naturally low-fat food. Foods with low total fat but containing appreciable amounts of essential unsaturated fatty acids are generally recommended for reducing excessive caloric intake and lowering the risk of obesity and cardiovascular diseases [44]. Therefore, *P. globosa* may represent a healthy dietary alternative for consumers seeking lean animal protein sources.

5. Conclusion

To the best of our knowledge, this is the first comprehensive study comparing the proximate composition and fatty acid profile of *P. globosa* during the active and aestivation periods. The results demonstrate that the nutritional quality of this freshwater apple snail is strongly influenced by its physiological state. During the active period, *P. globosa* exhibited a protein-rich, low-fat nutritional profile, characterized by high protein content (32.00 g/100 g dry weight), low lipid content (2.84 g/100 g dry weight), and a lipid fraction dominated by polyunsaturated fatty acids (40.51%), indicating its potential as a valuable source of high-quality protein and essential fatty acids for human nutrition. In contrast, aestivation induced pronounced biochemical changes, including reductions in carbohydrate, monounsaturated fatty acid, and polyunsaturated fatty acid contents, together with increases in protein, fat, ash, moisture, and saturated fatty acids. These compositional changes reflect metabolic adaptations that enable survival during prolonged dormancy through the preferential utilization of carbohydrate reserves and unsaturated fatty acids as energy substrates. The nutritional quality indices further demonstrated that *P. globosa* collected during the active period possessed superior dietary quality because of its higher PUFA/SFA ratio and greater abundance of essential fatty acids. Although the PUFA content declined during aestivation, the lower n-6/n-3 ratio remained within a nutritionally acceptable range. Consistent with the recommendations of the FAO/WHO Expert Consultation, the nutritional value of dietary lipids should be assessed based on adequate intake of both omega-6 and omega-3 fatty acids rather than adherence to a fixed n-6/n-3 ratio. Overall, the present findings establish *P. globosa* as a promising, affordable, and sustainable freshwater food resource with considerable nutritional value, particularly when harvested during the active period. The observed seasonal variations provide valuable baseline information for optimizing harvesting strategies, improving utilization of this underexploited aquatic resource, and supporting food and nutrition security. Furthermore, understanding these seasonal biochemical adaptations will contribute to the sustainable management and conservation of *P. globosa* populations under changing environmental and climatic conditions.

6. Recommendations

Future studies should investigate which environmental factors and food habits influence the fatty acid and proximate composition of *P. globosa* during the longer seasonal cycles and wider geographic regions. Moreover, future studies should develop sustainable harvesting guidelines and aquaculture protocols to protect natural resources for future generations.

Abbreviations

FAME	Fatty Acid Methyl Esters
SFAs	Saturated Fatty Acids
MUFA	Monounsaturated Fatty Acids
PUMAs	Polyunsaturated Fatty Acids
WHO	World Health Organization
FAO	Food and Agriculture Organization of the United Nations
RDA	Recommended Dietary Allowance
DRI	Dietary Reference Intakes
BCSIR	Bangladesh Council of Scientific and Industrial Research

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Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

Table A1. Proximate Composition during Active and Aestivation Periods.

Test Parameters	Result of Active Period	Result of Aestivation Period
Moisture (g/100g)	6.4	7.37
Ash (g/100g)	18.21	26.04
Protein (g/100g)	32	33.87
Fat (g/100g)	2.84	7.97
Carbohydrate (g/100g)	40.55	24.75

Table A2 Seasonal Changes in Fatty Acid Composition During Aestivation.

Symbol	Active Period	Aestivated Period	Category
C4:0	0	0.17	SFA
C6:0	0	0.06	SFA
C11:0	0	0.11	SFA
C12:0	0	0.41	SFA
C14:0	0.77	10.15	SFA
C15:0	0.62	2.73	SFA
C16:0	14.61	19.62	SFA
C17:0	0.55	2.23	SFA
C18:0	6.21	5.01	SFA
C20:0	0.56	1.18	SFA
C22:0	0.38	0.62	SFA
C23:0	0	0.68	SFA
C24:0	0	0.13	SFA
Total SFA	23.7	43.1	TOTAL
C16:1 (Ω-7) trans	0	0.6	MUFA
C16:1 (Ω-7)	0.7	4.01	MUFA
C18:1 trans	0	1.24	MUFA
C18:1 cis	0	0.55	MUFA
C18:1 (Ω-9)	23.41	8.88	MUFA
C18:1 (Ω-7)	0.76	4.26	MUFA
C20:1 (Ω-9)	4.49	0.82	MUFA
Total MUFA	29.36	20.36	TOTAL
C18:2 (Ω-6)	0	1.65	PUFA
C18:3 trans	0	0.36	PUFA
C18:2 (Ω-6)	34.01	6.04	PUFA
C18:3 (Ω-3)	2.02	2.34	PUFA

Symbol	Active Period	Aestivated Period	Category
C20:2	1.07	1.21	PUFA
C20:3	2.78	0.72	PUFA
C20:4 (Ω-6)	0	2.12	PUFA
C20:5 (Ω-3)	0.29	0.13	PUFA
C22:2	0.34	0	PUFA
C22:1 (Ω-9)	0	0.46	PUFA
Heneicosanoic	0	0.52	PUFA
Total PUFA	40.51	15.55	TOTAL
Unknown	5.74	20.89	OTHER

Table A3. *Lipid quality indices during aestivated and active periods.*

Lipid quality index	Aestivated Period (%)	Active Period (%)
PUFA/SFA	0.34	1.71
Σ n-6	9.81	34.35
Σ n-3	3.55	5.09
Σ n-6 / Σ n-3	2.76	6.75

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