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The impact of dietary acid load on kidney function in individuals with chronic kidney disease: A literature review

Dampak beban asam makanan terhadap fungsi ginjal pada individu dengan penyakit ginjal kronis: Sebuah tinjauan literatur

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Abstract

Chronic Kidney Disease (CKD) has been increasingly associated with dietary patterns, particularly a high Dietary Acid Load (DAL). Diets rich in animal protein and low in fruits and vegetables may contribute to metabolic disturbances that negatively affect the kidney function. This literature review aimed to evaluate the relationship between DAL and kidney function in individuals with CKD. A literature search was conducted using PubMed, ScienceDirect, and Google Scholar for studies published between January and June 2025. A total of 19,040 articles were included. After screening and eligibility assessment using the PRISMA approach, six studies were included. Review articles, clinical trials, and animal studies were excluded from the study. Data were analyzed descriptively to identify the association between DAL and renal outcomes in patients with CKD. The findings consistently indicated that a high DAL was associated with impaired kidney function, including lower serum bicarbonate levels, reduced glomerular filtration rate (GFR), and increased serum creatinine concentrations. Variations in study outcomes were observed due to differences in DAL assessment methods, such as dietary intake analysis and urinary net endogenous acid production (NEAP) measurement. In conclusion, a High DAL may contribute to CKD progression. Further longitudinal and interventional studies are required to clarify the causal effects of DAL reduction on renal health.

Keywords: Chronic kidney disease, dietary acid load, kidney function, serum bicarbonate

Abstrak

Penyakit Ginjal Kronis (PGK) semakin banyak dikaitkan dengan pola konsumsi makanan, terutama tingginya Dietary Acid Load (DAL). Pola makan tinggi protein hewani dan rendah buah serta sayur dapat memicu gangguan metabolik yang berdampak negatif terhadap fungsi ginjal. Tinjauan literatur ini bertujuan untuk mengevaluasi hubungan antara DAL dan fungsi ginjal pada individu dengan PGK. Metode yang digunakan melalui penelusuran literatur dilakukan melalui PubMed, ScienceDirect, dan Google Scholar terhadap artikel yang dipublikasikan pada Januari hingga Juni 2025. Sebanyak 19.040 artikel berhasil diidentifikasi. Setelah proses penyaringan dan penilaian kelayakan menggunakan pendekatan PRISMA, diperoleh enam artikel yang memenuhi kriteria inklusi. Artikel ulasan, uji klinis, dan penelitian pada hewan dikeluarkan dari analisis. Data dianalisis secara deskriptif untuk mengidentifikasi hubungan DAL dengan luaran fungsi ginjal pada pasien PGK. Hasil, sebagian besar penelitian menunjukkan bahwa DAL yang tinggi berhubungan dengan penurunan fungsi ginjal, ditandai dengan rendahnya kadar bikarbonat serum, penurunan laju filtrasi glomerulus (LFG), serta peningkatan kadar kreatinin serum. Perbedaan hasil antarpenelitian dipengaruhi oleh

variasi metode penilaian DAL, seperti analisis asupan makanan dan pengukuran net endogenous acid production (NEAP) urin. Kesimpulan, DAL yang tinggi berpotensi mempercepat progresivitas PGK. Penelitian longitudinal dan intervensi lebih lanjut diperlukan untuk memastikan efek penurunan DAL terhadap perbaikan kesehatan ginjal

Kata Kunci: Dietary acid load, fungsi ginjal, penyakit ginjal kronis, serum bikarbonat

Introduction

Chronic kidney disease (CKD) is a disorder in which the kidneys are damaged and unable to function correctly, causing excessive accumulation of fluids and waste substances in the blood (Hamidianshirazi & Ekramzadeh, 2021). The rapid course of kidney disease can be altered by modifying the progression of CKD risk factors to reduce the risk of end-stage renal disease (ESRD) and other complications of CKD (Banerjee et al., 2016). Dietary modification is one of the strategies that can be implemented. Diet can affect the acid-base status, which must be removed from the kidneys to maintain acid-base homeostasis (Frassetto et al., 2018). Furthermore, excess acid retention in the body affects the level of renal function, which can exceed the ability of the impaired kidney to adapt in response to additional factors that influence acid excretion, either maintaining or hindering it (Nagami & Hamm, 2017a).

Dietary acid load (DAL) is an index that reflects the net effect of acid-producing foods (e.g., protein-source foods) and base-inducing foods (e.g., fruits and vegetables) in the diet (Banerjee et al., 2015). Dietary acid load has previously been used in research related to the risk factors or complications of chronic kidney failure. Previous studies have reported that dietary acid load is linked to an elevated risk of hypertension (Krupp et al., 2018), diabetes mellitus (Kiefte-de Jong et al., 2017), cardiovascular diseases (Han et al., 2016), damage to bone microstructures (de Jonge et al., 2017), and death. The kidneys are one of the organs that help maintain acid-base balance, and considering the relationship between acid-producing and base-producing foods provides a novel target for evaluating diet quality and improving disease management in chronic kidney disease (Naber & Purohit, 2021).

Several mechanisms are associated with the relationship between DAL and CKD risk. DAL-induced metabolic acidosis caused by DAL is associated with enhanced endothelial activity, which may contribute to renal damage. Additionally, acid accumulation may induce aldosterone production, activating the renin-angiotensin system and promoting the initiation and progression of CKD (Mofrad et al., 2021). Excessive protein and phosphorus intakes can contribute to renal damage through sustained increases in glomerular pressure and hyperfiltration. However, the quality of the protein digested or the production of the base becomes a more important determinant than the quantity of protein digested (Banerjee et al., 2014; Osuna-Padilla et al., 2019).

An experimental study demonstrated that reducing DAL, either through $NaHCO_3$ supplementation and/or the consumption of base-producing fruits and vegetables, slowed the decline in GFR and urinary markers of renal injury in patients with CKD (Tanaka et al., 2025). Another study involving 15,055 participants without CKD over a 21-year follow-up reported that a higher DAL was significantly associated with an increased risk of CKD (Rebholz et al., 2015). Additionally, higher serum bicarbonate concentrations within the normal range are associated with a lower risk of both mortality and CKD progression, with serum bicarbonate identified as an independent predictor of CKD development (Fukasawa et al., 2022).

High DAL scores are associated with an increased risk of CKD and decreased urinary pH. These findings confirm that a diet high in fruits and vegetables, as natural sources of alkali, helps maintain the body's acid–base balance and protects kidney function (Mofrad et al., 2021). In addition, Silva et al. (2021) confirmed the existence of an association between DAL and renal function, with a high DAL contributing to decreased renal function (Silva et al., 2021). The previous study included the general population. This review specifically evaluates the evidence among patients with CKD who have altered acid-base management. Previous systematic reviews have examined the association between DAL and

kidney outcomes in general or mixed populations. This review focuses specifically on patients with CKD and updates the evidence to 2025, with an emphasis on specific biomarkers such as eGFR, creatinine, and bicarbonate. Thus, this study aimed to evaluate the association between higher DAL and renal function, including GFR, creatinine, bicarbonate serum, and albuminuria, among individuals with CKD.

Methods

This research was conducted through a literature study or literature review based on three databases: PubMed, ScienceDirect, and Google Scholar. The search strategy used a combination of keywords, subjects, and titles: dietary acid load, net endogenous acid production, kidney function, glomerular filtration rate, urea, albuminuria, and chronic kidney disease. The searches were conducted from January to June 2025. The inclusion criteria for the literature review were 1) articles published in the last 10 years (2015-2025); 2) using the cohort or cross-sectional method; 3) in English; 4) subjects with an age of >18 years; and 5) articles that could be accessed in full text online. To simplify the study, the exclusion criteria were studies conducted on adolescents or children were excluded.

The article search process uses techniques, including Boolean search, with the keywords "dietary acid load" OR "net endogenous acid production" AND "kidney function" OR "glomerulus filtration rate" OR "urea" OR "serum bicarbonate" AND "chronic kidney disease." Two reviewers independently screened the titles and abstracts for eligibility. Any disagreement regarding inclusion was resolved through discussion until a consensus was reached. Only studies involving adults with chronic kidney disease were included. The primary outcome was kidney function, assessed using eGFR, serum creatinine, albuminuria, urine pH, and serum bicarbonate levels.

A total of 225 articles were obtained from the PubMed database, 415 from the ScienceDirect database, and 18,400 from Google Scholar. According to the inclusion criteria, six studies met the requirements and were considered eligible for review (Figure 1). Publication bias may exist because only three databases were searched and grey literature was not included. Google Scholar results were limited to the first 300 hits because of practical constraints.

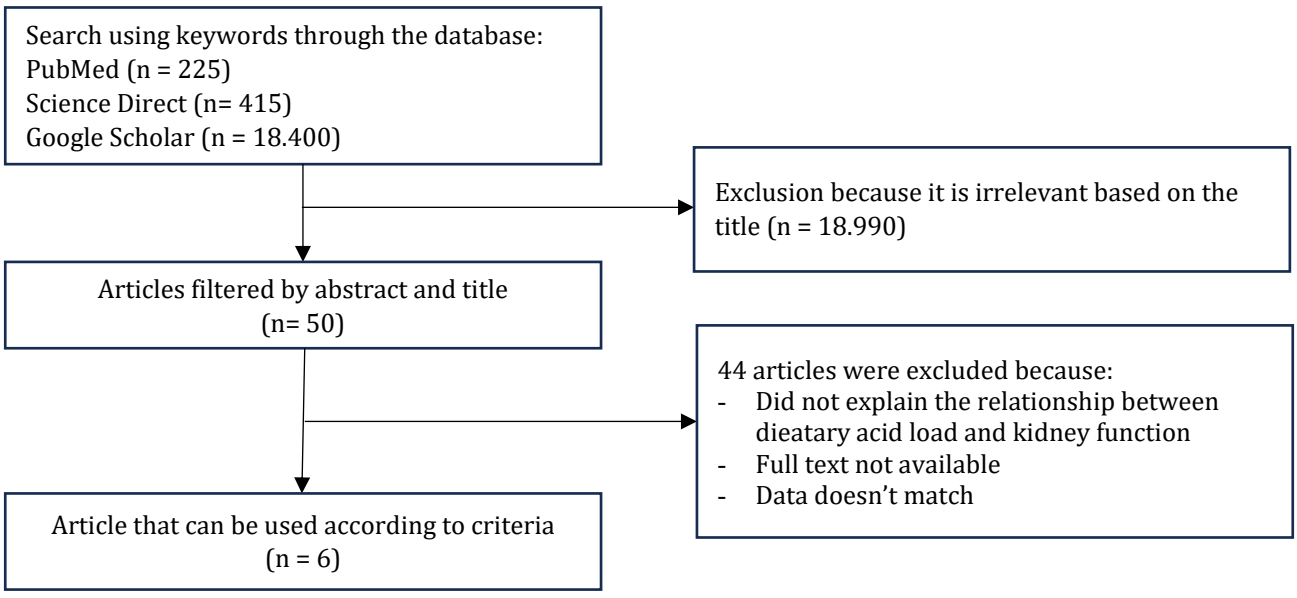

Figure 1. Literature search flow

The analytical approach employed in this literature review is a descriptive method that explains and narrates the results of various studies presented in narrative form. The researchers grouped articles on the DAL and renal function in individuals with CKD.

Articles that have undergone a selection process are then reviewed by focusing on three main criteria for research

quality: topics of interest, articles relevant to the purpose of the literature review, and article suitability. Data extraction is presented in the form of a table to answer the objectives of this study: 1) author and year, 2) method (research design, subject, location, data collection method, statistical analysis), 3) result, and 4) conclusion. Data analysis described the relationship between DAL and renal function in individuals with CKD.

Result and Discussion

Six articles met the inclusion criteria based on an article search through three databases (PubMed, ScienceDirect, and Google Scholar) and a selection process**.** The research objective of the six relevant articles was to determine the relationship between Dietary Acid Load (DAL) and kidney function in individuals with CKD. Kidney function was assessed using serum bicarbonate, Glomerular Filtration Rate (GFR), and creatinine (Cre) levels.

Table 1. Dietary Acid Load (DAL) and kidney function

Author, year	Study design	Population	DAL metrice	Outcome	Main findings
Ikizler et al. (2016)	Cross-sectional	Participants included 42 individuals with stage 3 – 5 CKD from nephrology clinics in the Pacific Northwest and 21 control subjects with eGFR ≥60mL/min/1.73m^2	Potential Renal Acid Load (PRAL) Net Endogenous Acid Production (NEAP)	Serum bicarbonate and insulin sensitivity	An association was observed between DAL and serum bicarbonate levels, but not with insulin sensitivity.
Angeloco et al. (2020)	Cross-sectional	A total of 100 adults (≥ 20 years old) diagnosed with stages 3 and 4 CKD	Potential Renal Acid Load (PRAL) Net Endogenous Acid Production (NEAP)	Serum bicarbonate	DAL was associated with serum bicarbonate levels in patients with stages 3 and 4 CKD.
Koor et al. (2025)	Cross-sectional	90 CKD patients	Potential Renal Acid Load (PRAL) Net Endogenous Acid Production (NEAP)	Biochemical indices, such as Glomerular Filtration Rate (GFR) and Creatinine (Cre	DAL indices in patients with CKD showed no significant correlation with kidney function.
Moghari et al. (2022)	Cross-sectional	122 CKD patients with hemodialysis	Potential Renal Acid Load (PRAL) Net Endogenous Acid Production (NEAP)	Pre-dialysis serum bicarbonate level and serum electrolytes	Patients with ESRD with lower DAL exhibited higher pre-dialysis serum bicarbonate levels.
Koba et al. (2019)	Cross-sectional	96 outpatients with CKD	Net Endogenous Acid Production (NEAP)	eGFR	Among Japanese patients with CKD, inadequate fruit and vegetable intake may increase DAL, thereby affecting the progression of kidney dysfunction.
Scialla et al. (2016)	Longitudinal cohort	A total of 3.939 patients with early to moderate stages of CKD	Net Endogenous Acid Production (NEAP)	eGFR	No relationship was found between the diet-based estimates of nonvolatile acid load and CKD progression. This finding may be attributed to the higher accuracy of urine-based measures compared with questionnaire-based assessments, lower dependence on total energy intake, or the advantage of a larger sample size.

This literature review aims to update the scientific literature on the relationship between the DAL and kidney function, including GFR, creatinine, serum bicarbonate, and albuminuria, among individuals with CKD. However, some studies differed in terms of DAL calculation and measured outcomes. In addition, different diets and geographical contexts may influence variations in the results between studies.

Most studies support the association between a high DAL and lower kidney function. A summary of the analysis results of the six studies is presented. Four articles on DAL and serum bicarbonate levels were reviewed (Table 1). The results showed that DAL was associated with serum bicarbonate levels. Dietary Acid Load (DAL) is a measure of acid load derived from food, considering the potential renal acid load (PRAL) of food ingredients, where food ingredients high in protein are the primary sources of dietary acid load (Mahan & Raymond, 2017; Wieërs et al., 2024). The DAL value can be estimated using the Net Endogenous Acid Production (NEAP) equation (mEq/day) by Frassetto et al. and Net Endogenous Acid Production (NEAP) by Remer et al., as well as the Potential Renal Acid Load (PRAL) in urine (Remer, 2000). The kidneys, which are central to acid-base regulation, must excrete the acid-base load influenced by dietary intake (Hamidianshirazi & Ekramzadeh, 2021). The kidneys reabsorb and maintain bicarbonate (HCO_3^-) production by eliminating non-volatile acids generated from metabolic activity in the form of endogenous acid production (EAP) (Osuna-Padilla et al., 2019; Wieërs et al., 2024).

The kidneys produce non-volatile acids when organic sulfur from the amino acids methionine and cysteine is oxidized into inorganic sulfates. These acids can be balanced by bases derived from the metabolism of organic anions, such as citrate and malate, found in fruits and vegetables. When the DAL increases due to high protein consumption, the kidneys increase bicarbonate formation above normal levels by increasing ammonium (NH_4^+) excretion. Ammonium accumulation in the renal tubules causes toxicity and damage (Kramer, 2019).

High DAL scores also activate the renin–angiotensin system and increase endothelin-1 production, thereby accelerating kidney injury and fibrosis (Tanaka et al., 2025). In patients with CKD, decreased renal function causes the kidneys to steadily worsen in their ability to remove acid because the kidneys' ability to produce new bicarbonate decreases (Nagami & Hamm, 2017a; Ravikumar et al., 2022). High DAL can cause an adaptive response that facilitates acid excretion, triggering further damage to kidney function and accelerating kidney disease development. Reduction of the DAL in individuals with CKD has been shown to elevate serum bicarbonate levels, thereby attenuating the decline in GFR and reducing urinary albumin excretion. This, in turn, reduces the risk of progression to kidney failure (Navaneethan et al., 2019). In addition, ammonia excretion and the renal ability to reabsorb bicarbonate progressively decline, but titratable acid excretion is maintained, causing impaired renal function (Nagami & Hamm, 2017a). In individuals with CKD, the kidneys exhibit a reduced threshold for bicarbonate loss in the urine.

Following the intake of acid-producing foods, the kidneys enhance the synthesis and elimination of ammonia, under normal conditions. However, in patients with CKD, the inability to produce and excrete adequate amounts of ammonia contributes to acid retention and the development of metabolic acidosis. During the progression of kidney disease and decline in GFR, the remaining nephrons can no longer optimally handle DAL, leading to high acid accumulation in the body. In individuals with CKD, the utilization of glutamine, the primary substrate for ammonia production, is impaired compared to that in individuals with normal renal function (Mohiuddin & Khattar, 2023; Nagami & Hamm, 2017b).

The NKF-KDOQI nutrition guidelines advise adults with stage 1–4 CKD to lower their DAL by consuming more fruits and vegetables, which may help slow the progression of kidney function decline. However, patients aiming to lower their NEAP through higher fruit and vegetable intake should be cautious and regularly monitor their potassium levels (Tanaka et al., 2025).

Serum bicarbonate levels are one of the parameters often used to assess the physiological effects of DAL. High acid loads were inversely proportional to serum bicarbonate levels. This is because the body uses bicarbonate to neutralize excess acids. Lower

serum bicarbonate levels are an underlying cause of CKD progression (Kim, 2021; Raphael et al., 2020). High blood bicarbonate concentrations may reduce the risk of CKD development and mortality.

DAL plays a crucial role in the health of patients with CKD because lower bicarbonate levels in the bloodstream are also linked to worsening kidney function and a higher risk of death (Angeloco et al., 2020; Mofrad et al., 2021). Ikizler et al. found that DAL is related to renal acid elimination and is negatively correlated with serum bicarbonate levels. Ikizler et al. found that participants with a low NEAP also had higher serum bicarbonate concentrations (Ikizler et al., 2016). A separate study by Angeloco et al. also identified a significant inverse relationship between DAL and serum bicarbonate levels in individuals with stages 3 and 4 CKD. These findings suggest that animal-based protein has a stronger impact on lowering serum bicarbonate levels than plant-based protein (Angeloco et al., 2020).

Dietary acid intake contributes to acidosis across the entire spectrum of renal functions (Ikizler et al., 2016). Animal protein has a greater effect on serum bicarbonate levels than that of plant protein. Foods that are potentially acidic may damage the kidney tubules by raising ammonia levels within the nephrons (Banerjee et al., 2015). In individuals with impaired renal function, this condition can lead to metabolic acidosis. Therefore, patients with CKD are recommended to adjust their intake of acidic foods to lower their daily acid production and help prevent metabolic acidosis. In addition, this food modification aims to avoid several negative consequences of metabolic acidosis in patients with CKD (Angeloco et al., 2020; Siener, 2018; Vincent-Johnson et al., 2023).

Moghari et al. (2023) reported that nearly half (47.5%) of the patients had predialysis serum bicarbonate levels lower than the recommended range. Lower DAL scores were significantly inversely related to pre-dialysis bicarbonate concentrations in the blood. This suggests that a lower acid load intake may help patients with ESRD maintain pre-dialysis bicarbonate concentrations in the blood within the suggested range (Moghari et al., 2023). Serum bicarbonate levels were positively related to DAL compared to protein levels. This indicates that the proportion of intake of potentially acidic and potentially basic foods must be measured when developing nutrition guidelines for patients with CKD (Angeloco et al., 2020).

These studies confirm that DAL is a modifiable factor contributing to metabolic acidosis in patients with CKD. Individuals with CKD should adopt nutritional strategies that lower their DAL to minimize daily acid production and mitigate the risk of metabolic acidosis. This is because, based on the findings of the articles in the literature review, DAL plays a vital role in the nutritional management of CKD and contributes to increased serum bicarbonate levels.

Other indicators often used to measure kidney function include creatinine and GFR. Four studies reviewed the DAL and Glomerular Filtration Rate (GFR), and creatinine (Cre) (Table 1). The results of the literature show a decrease in GFR in people who consume higher NEAP levels (Toba et al., 2019). The crude model showed a relationship between DAL, GFR, and creatinine. After adjusting for confounding factors through the adjusted model, the relationship became insignificant (Koor et al., 2024).

DAL is a critical determinant of CKD progression and severity (Rusdi et al., 2023). A more appropriate diet may be more effective in protecting the kidneys from damage. A healthy diet can prevent a decline in GFR during the initial phases of CKD (Rysz et al., 2017). Patients with impaired renal function are advised to restrict the consumption of specific food items to minimize the accumulation of unmetabolized waste products and reduce the risk of CKD-related complications.

Dietary acid load (DAL) reduces the glomerular filtration rate (GFR). Toba et al. (2019) found that excess NEAP was related to declined kidney function and was caused by less fruit and vegetable intake in CKD patients in Japan. Toba et al. (2019) also reported that elevated NEAP values are associated with the presence of albuminuria. Fruit and vegetable intake in stage 2 CKD patients with preserved renal function did not significantly affect NEAP, significantly inhibiting the progression of renal impairment. Further investigation is necessary to establish stage-specific recommendations for fruit and vegetable consumption in individuals with CKD (Toba et al., 2019).

Rusdi et al. (2023) found a significant correlation between DAL and renal function in patients with CKD undergoing HD ($p < 0.05$). As a source of acid load, protein is one of the physiological regulators of GFR linked to an elevated risk of CKD onset and progression via mechanisms involving renal hyperfiltration. A diet characterized by a DAL promotes ammonia genesis by tubular epithelial cells to buffer the elevated luminal hydrogen ion concentration, resulting in tubular hypertrophy and glomerular hyperfiltration. The rise in intratubular hydrogen ion levels is associated with the enhanced synthesis of endothelin-1, angiotensin II, and aldosterone, ultimately contributing to a decline in GFR. This occurs when an individual consistently consumes a high-DAL diet over an extended period (Osuna-Padilla et al., 2019). The decrease in GFR due to DAL is also associated with an increase in creatinine concentration as a consequence of DAL's high impact of DAL on renal function (Rusdi et al., 2023).

Scialla et al. (2017) observed that reduced 24-hour net acid excretion was associated with an elevated risk of CKD progression in individuals with diabetes. However, in this study, the acid load estimations derived from dietary intake data did not demonstrate a significant association with CKD progression in patients with diabetes. This discrepancy may be attributed to the fact that 24-hour net acid excretion does not accurately capture the predominant dietary patterns in individuals with CKD. Moreover, it is important to recognize that urinary biomarkers of acid load have not been thoroughly validated as reliable indicators of dietary intake in the CKD population (Scialla et al., 2017). This suggests that the underlying cause of CKD progression associated with low NAE may be attributed to alterations in endogenous acid generation that are not solely dependent on the diet.

A high DAL was consistently associated with lower kidney function, although causality cannot be inferred due to the observational nature of the included studies. Dietary Acid Load (DAL) may reduce GFR and elevate creatinine levels. In addition, a higher DAL correlates with renal stress and may accelerate CKD progression. DAL is a modifiable dietary factor that influences renal function.

The literature search was limited to three databases and excluded grey literature, which may have led to publication bias. The included studies showed high heterogeneity in DAL assessment methods, populations, and study designs, most of which were cross-sectional, preventing causal inference. Therefore, the findings should be interpreted with caution, and further standardized longitudinal and interventional studies are required to confirm the causal role of the DAL in CKD progression. In the article selection process, there were limited inclusion criteria for English articles. This may have resulted in the loss of several articles that were worthy of inclusion. However, the selected database was the most comprehensive.

Conclusion

Dietary Acid Load (DAL) may influence acid-base balance and renal function, especially in patients with CKD. Diets characterized by high DAL typically rich in animal protein and low in fruits and vegetables may be associated with lower serum bicarbonate levels, reduced glomerular filtration rate (GFR), and higher serum creatinine levels, although causality cannot be inferred due to the observational nature of the included studies. In conclusion, managing DAL is key to preserving kidney function, preventing metabolic acidosis, and controlling outcomes in patients with CKD. It may be possible to decrease the development of CKD by including low-DAL eating habits in the nutritional management of individuals with CKD.

Practical dietary strategies to reduce the DAL include increasing the consumption of fruits and vegetables as natural alkali sources, moderating animal protein intake, and emphasizing plant-based protein alternatives. Incorporating these low-DAL patterns into nutritional management may help delay CKD progression and mitigate metabolic acidosis in patients with CKD. However, further research is needed to refine dietary recommendations based on CKD stage and individual patient requirements.

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