TABLE 5 ORs and 95% CIs of diabetic nephropathy based on micronutrient patterns among cases and controls.

Variables	Reference (low)	Mineral pattern		Water-soluble vitamin pattern		Fat-soluble vitamin pattern	
		High	*p*-value	High	*p*-value	High	*p*-value
Crude	1.00 (ref)	0.56 (0.32–0.97)	**.03**	0.73 (0.42–1.26)	.26	0.56 (0.32–0.97)	**.03**
Model 1	1.00 (ref)	0.51 (0.28–0.95)	**.03**	0.60 (0.33–1.10)	.09	0.53 (0.29–0.98)	**.04**

Note: Logistic regression was used. Low and high are presented as lower and higher adherence of median.
ORs (95% CI) is shown across patterns. *p* value < .05 was showed by bold font.
Model 1: Adjusted for energy intake, age, physical activity, hemoglobin, serum vitamin D3, and albumin.

The underlying mechanistic action might include numerous pathways; for instance, its antioxidant capacity, where vitamin E alters IRS1 phosphorylation, and thus, impacts insulin signaling (Gray et al., 2011). Additionally, vitamin E was found to directly regulate gene expression such as PPAR-δ, which plays a crucial role in insulin sensitivity (Landrier et al., 2009).

Several mineral substances are activating cofactors and coenzymes for metabolism control, oxidative stress, and genetic transcription. The deficiency of mineral substances has been shown to have a significant association with T2DM (Guo et al., 2020). An adequate selenium intake can act as an insulin-mimetic to attenuate diabetes, with the role of reducing glucose and insulin tolerance, and therefore, preventing hepatic insulin resistance (Zhou et al., 2013). Indeed, chromium plays a vital role in glucose metabolism by augmenting the binding of insulin to INSR (Cefalu & Hu, 2004), where mechanisms underlying this beneficial function of chromium might partly be explained by the enhancement of GLUT2 expression and the activation of the PI3K/AKT pathway in skeletal muscle (Panchal et al., 2017). Zinc is a significant component of enzymes that play important roles in regulating insulin sensitivity and glucose homeostasis (Russell et al., 2016). Recent research indicated that, in patients with T2DM, the concentrations of zinc in plasma and tissues are generally lower (Russell et al., 2016). Another substance, magnesium, was suggested to reduce the risk of cardiovascular diseases in T2DM patients. However, not all the minerals are good for patients with DN; for instance, high sodium intake leads to a higher risk of hypertension and cardiovascular diseases (Zhao et al., 2016). Moreover, sodium intake enhances natriuresis via the PPAR-δ/SGLT2 pathway and subsequently regulates glucose metabolism of T2DM patients (Zhao et al., 2016). Restricted sodium intake can lead to improvements in blood pressure in such patients. Although, high salt intake and urinary protein excretion have been shown to be related to annual creatinine clearance decline in patients with DN (Kanauchi et al., 2015). Throughout a weakening in renal function, potassium excretion is decreased leading to an accumulation in body tissues (Sulaiman, 2019). Hence, potassium intake, particularly from foods such as grains, potatoes, corn, soybean, nuts, tomatoes, banana, kiwi, etc., should be restricted (Sulaiman, 2019). Phosphorus excretion is also decreased throughout chronic kidney impairment leading to increased blood phosphorus levels (Sulaiman, 2019).

To the best of our knowledge, this is the first study to have assessed the association between micronutrient patterns and the risk of DN in a case–control design. However, our study has some limitations. The case–control nature of the study precludes cause-and-effect conclusions. In addition, there might be small errors in the dietary assessment, mostly due to (mis)recalling the data and misclassification errors by using FFQ. Moreover, our study only included women, and thus, results are not generalizable to men.

5 | CONCLUSION

In conclusion, the results of our investigation suggest that higher intakes of several micronutrients, such as vitamins E, D, magnesium, and selenium decrease the risk of DN, whereas high intake of sodium is associated with an increased risk of incident DN. Our findings emphasize that dietary sources of renal-protective nutrients should be encouraged among the general population. However, whether this knowledge can be exploited for DN prevention purposes must be ascertained in follow-up studies.

ACKNOWLEDGMENTS

The authors thank the study participants for their cooperation and assistance in physical examinations. This study was supported by TUMS.

FUNDING INFORMATION

Tehran University of Medical Sciences and Health Services funded and supported the present study (Grant number: 94-04-161-31155).

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no competing interest.

DATA AVAILABILITY STATEMENT

The data are not publicly available because of containing information that could compromise the privacy of the research. The datasets used and analyzed during the current study will be available from the corresponding author, Khadijeh Mirzaei, upon reasonable request.

ETHICAL APPROVAL

This research was conducted according to the Declaration of Helsinki. The study protocol was approved by the ethics committee of Tehran University of Medical Sciences (Ethic Number: IR.TUMS.REC.1395.2644), and by the ethics committee of Semnan University of Medical Sciences (Ethic Number: IR.SEMUMS.REC.1395.66).

INFORMED CONSENT

Written informed consent was obtained from all subjects and/or their legal guardian(s).

CONSENT FOR PUBLICATION

All authors listed approved the final manuscript and consent for publication.

ORCID

Niki Bahrampour https://orcid.org/0000-0002-7408-8602

REFERENCES

Ahn, H. J., Min, K. W., & Cho, Y. O. (2011). Assessment of vitamin B(6) status in Korean patients with newly diagnosed type 2 diabetes. *Nutrition Research and Practice*, *5*(1), 34–39.

Anders, H. J., Huber, T. B., Isermann, B., & Schiffer, M. (2018). CKD in diabetes: Diabetic kidney disease versus nondiabetic kidney disease. *Nature Reviews. Nephrology*, *14*(6), 361–377.

Aziz, M., Jalilpiran, Y., Nekouimehr, M., Fattahi, S., Mokhtari, P., Jayedi, A., Yekaninejad, M. S., & Mirzaei, K. (2021). Dietary protein sources and risk of diabetic nephropathy in women: A case–control study. *BMC Endocrine Disorders*, *21*(1), 174.

Basit, A., Basit, K. A., Fawwad, A., Shaheen, F., Fatima, N., Petropoulos, I. N., Alam, U., & Malik, R. A. (2016). Vitamin D for the treatment of painful diabetic neuropathy. *BMJ Open Diabetes Research & Care*, *4*(1), e000148.

Beydoun, M. A., Fanelli-Kuczmarski, M. T., Canas, J.-A., Beydoun, H. A., Evans, M. K., & Zonderman, A. B. (2018). Dietary factors are associated with serum uric acid trajectory differentially by race among urban adults. *The British Journal of Nutrition*, *120*(8), 935–945.

Bjornstad, P., Lanaspa, M. A., Ishimoto, T., Kosugi, T., Kume, S., Jalal, D., Maahs, D. M., Snell-Bergeon, J. K., Johnson, R. J., & Nakagawa, T. (2015). Fructose and uric acid in diabetic nephropathy. *Diabetologia*, *58*(9), 1993–2002.

Borrelli, S., Provenzano, M., Gagliardi, I., Michael, A., Liberti, M., De Nicola, L., Conte, G., Garofalo, C., & Andreucci, M. (2020). Sodium intake and chronic kidney disease. *International Journal of Molecular Sciences*, *21*(13), 4744.

Cefalu, W. T., & Hu, F. B. (2004). Role of chromium in human health and in diabetes. *Diabetes Care*, *27*(11), 2741–2751.

Cheung, C. L., Sahni, S., Cheung, B. M., Sing, C. W., & Wong, I. C. (2015). Vitamin K intake and mortality in people with chronic kidney disease from NHANES III. *Clinical Nutrition*, *34*(2), 235–240.

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381–1395.

de Oliveira Otto, M. C. C., Alonso, A., Lee, D. H., Delclos, G. L., Jenny, N. S., Jiang, R., Lima, J. A., Symanski, E., Jacobs Jr, D. R., & Nettleton, J. A. (2011). Dietary micronutrient intakes are associated with markers of inflammation but not with markers of subclinical atherosclerosis. *The Journal of Nutrition*, *141*(8), 1508–1515.

Esfahani, F. H., Asghari, G., Mirmiran, P., & Azizi, F. (2010). Reproducibility and relative validity of food group intake in a food frequency questionnaire developed for the Tehran lipid and glucose study. *Journal of Epidemiology*, *20*(2), 150–158.

Fanelli, C., Dellê, H., Cavaglieri, R. C., Dominguez, W. V., & Noronha, I. L. (2017). Gender differences in the progression of experimental chronic kidney disease induced by chronic nitric oxide inhibition. *BioMed Research International*, *2017*, 2159739.

Farhadnejad, H., Asghari, G., Mirmiran, P., Yuzbashian, E., & Azizi, F. (2016). Micronutrient intakes and incidence of chronic kidney disease in adults: Tehran lipid and glucose study. *Nutrients*, *8*(4), 217.

Galindo, R. J., Beck, R. W., Scioscia, M. F., Umpierrez, G. E., & Tuttle, K. R. (2020). Glycemic monitoring and management in advanced chronic kidney disease. *Endocrine Reviews*, *41*(5), 756–774.

Garbossa, S. G., & Folli, F. (2017). Vitamin D, sub-inflammation and insulin resistance. A window on a potential role for the interaction between bone and glucose metabolism. *Reviews in Endocrine & Metabolic Disorders*, *18*(2), 243–258.

Gray, B., Swick, J., & Ronnenberg, A. G. (2011). Vitamin E and adiponectin: Proposed mechanism for vitamin E-induced improvement in insulin sensitivity. *Nutrition Reviews*, *69*(3), 155–161.

Guo, Y., Huang, Z., Sang, D., Gao, Q., & Li, Q. (2020). The role of nutrition in the prevention and intervention of type 2 diabetes. *Frontiers in Bioengineering and Biotechnology*, *8*, 575442.

Hu, X., Liu, W., Yan, Y., Liu, H., Huang, Q., Xiao, Y., Gong, Z., & Du, J. (2019). Vitamin D protects against diabetic nephropathy: Evidence-based effectiveness and mechanism. *European Journal of Pharmacology*, *845*, 91–98.

Iwakawa, H., Nakamura, Y., Fukui, T., Fukuwatari, T., Ugi, S., Maegawa, H., Doi, Y., & Shibata, K. (2016). Concentrations of water-soluble vitamins in blood and urinary excretion in patients with diabetes mellitus. *Nutrition and Metabolic Insights.*, *9*, 85–92.

Kanauchi, N., Ookawara, S., Ito, K., Mogi, S., Yoshida, I., Kakei, M., Ishikawa, S. E., Morishita, Y., & Tabei, K. (2015). Factors affecting the progression of renal dysfunction and the importance of salt restriction in patients with type 2 diabetic kidney disease. *Clinical and Experimental Nephrology*, *19*(6), 1120–1126.

Kim, H. Y. (2014). Nutritional intervention for a patient with diabetic nephropathy. *Clinical Nutrition Research*, *3*(1), 64–68.

Kim, Y., Hwang, S. D., Lim, J. H., Kim, M. Y., Kim, E. N., Choi, B. S., Kim, Y. S., Kim, H. W., & Park, C. W. (2019). Attenuated lymphatic proliferation ameliorates diabetic nephropathy and high-fat diet-induced renal lipotoxicity. *Scientific Reports*, *9*(1), 1994.

Landrier, J. F., Gouranton, E., El Yazidi, C., Malezet, C., Balaguer, P., Borel, P., & Amiot, M.-J. (2009). Adiponectin expression is induced by vitamin E via a peroxisome proliferator-activated receptor gamma-dependent mechanism. *Endocrinology*, *150*(12), 5318–5325.

Larkin, J. R., Zhang, F., Godfrey, L., Molostvov, G., Zehnder, D., Rabbani, N., & Thornalley, P. J. (2012). Glucose-induced down regulation of thiamine transporters in the kidney proximal tubular epithelium produces thiamine insufficiency in diabetes. *PLoS One*, *7*(12), e53175.

Lee, J., Oh, K.-H., & Park, S.-K. (2021). Dietary micronutrients and risk of chronic kidney disease: A cohort study with 12 year follow-up. *Nutrients*, *13*(5), 1517.

Lim, A. (2014). Diabetic nephropathy – complications and treatment. *International Journal of Nephrology and Renovascular Disease*, 361–381.

Mazidi, M., Gao, H.-k., & Kengne, A. P. (2018). Food patterns are associated with likelihood of CKD in US adults. *Scientific Reports*, *8*(1), 10696.

Molitch, M. E., DeFronzo, R. A., Franz, M. J., Keane, W. F., Mogensen, C. E., Parving, H. H., Steffes, M. W., & American Diabetes Association. (2004). Nephropathy in diabetes. *Diabetes Care*, *27*(Suppl 1), S79–S83.

Panchal, S. K., Wanyonyi, S., & Brown, L. (2017). Selenium, vanadium, and chromium as micronutrients to improve metabolic syndrome. *Current Hypertension Reports*, *19*(3), 10.

Piccoli, G. B., Alrukhaimi, M., Liu, Z. H., Zakharova, E., & Levin, A. (2018). What we do and do not know about women and kidney diseases; questions unanswered and answers unquestioned: Reflection on world kidney day and international Woman's day. *BMC Nephrology*, *19*(1), 66.

Ranjith Kumar, G. K., & Santhosh, P. (2015). Study of serum magnesium levels in type 2 diabetics. *International Journal of Medical Research and Review*, *3*(7). https://doi.org/10.17511/ijmrr.2015.i7.132

Russell, W. R., Baka, A., Björck, I., Delzenne, N., Gao, D., Griffiths, H. R., Hadjilucas, E., Juvonen, K., Lahtinen, S., Lansink, M., Loon, L. V., Mykkänen, H., östman, E., Riccardi, G., Vinoy, S., & Weickert, M. O. (2016). Impact of diet composition on blood glucose regulation. *Critical Reviews in Food Science and Nutrition*, *56*(4), 541–590.

Shibata, K., Ishikawa, A., & Kondo, T. (1997). Effects of dietary pyrazinamide on the metabolism of tryptophan to niacin in streptozotocin-diabetic rats. *Bioscience, Biotechnology, and Biochemistry*, *61*(10), 1679–1683.

Strippoli, G. F., Craig, J. C., Rochtchina, E., Flood, V. M., Wang, J. J., & Mitchell, P. (2011). Fluid and nutrient intake and risk of chronic kidney disease. *Nephrology*, *16*(3), 326–334.

Sulaiman, M. K. (2019). Diabetic nephropathy: Recent advances in pathophysiology and challenges in dietary management. *Diabetology and Metabolic Syndrome*, *11*(1), 7.

Thornalley, P. J., Babaei-Jadidi, R., Al Ali, H., Rabbani, N., Antonysunil, A., Larkin, J., Ahmed, A., Rayman, G., & Bodmer, C. W. (2007). High prevalence of low plasma thiamine concentration in diabetes linked to a marker of vascular disease. *Diabetologia*, *50*(10), 2164–2170.

Thornalley, P. J., & Rabbani, N. (2010). Vitamin B6, B9 and B12 in diabetic nephropathy—Beware. *Nature Reviews. Endocrinology*, *6*(9), 477–478.

Willett, W. C., Howe, G. R., & Kushi, L. H. (1997). Adjustment for total energy intake in epidemiologic studies. *The American Journal of Clinical Nutrition*, *65*(4 Suppl), 1220S–1228S; discussion 9S–31S.

Zhao, Y., Gao, P., Sun, F., Li, Q., Chen, J., Yu, H., Li, L., Wei, X., He, H., Lu, Z., Wei, X., Wang, B., Cui, Y., Xiong, S., Shang, Q., Xu, A., Huang, Y., Liu, D., & Zhu, Z. (2016). Sodium intake regulates glucose homeostasis through the PPARδ/adiponectin-mediated SGLT2 pathway. *Cell Metabolism*, *23*(4), 699–711.

Zhou, J., Huang, K., & Lei, X. G. (2013). Selenium and diabetes--evidence from animal studies. *Free Radical Biology & Medicine*, *65*, 1548–1556.

How to cite this article: Bahrampour, N., Mirzababaei, A., Abaj, F., Hosseininasab, D., Clark, C. C. T., & Mirzaei, K. (2023). The association between dietary micronutrient patterns and odds of diabetic nephropathy: A case–control study. *Food Science & Nutrition*, *00*, 1–11. https://doi.org/10.1002/fsn3.3306