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Original Article

Association between dietary antioxidant quality score and periodontitis: A cross-sectional study

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Association

Abstract *Background/purpose:* Evidence to date linking relation between dietary antioxidant quality score (DAQS) and periodontitis is limited. This study aimed to investigate the relationship between DAQS and periodontitis.
Materials and methods: In total, 9457 participants from the National Health and Nutrition Examination Survey 2009–2014 were enrolled in this cross-sectional study. The outcome was defined as periodontitis. DAQS was calculated by comparing the daily dietary intake of six micronutrients (vitamin A, C, E, selenium, magnesium and zinc) to the recommended daily intake, which was divided into three groups: low quality (1–2 points), medium quality (3–4 points) and high quality (5–6 points). Weighted logistic regression models were carried out to examine the association of DAQS and periodontitis. Meanwhile, this study investigated the effects of DAQS and periodontitis by stratified specific analyses based on diabetes and dyslipidemia.
Results: There were 4951 participants with periodontitis and 4506 non-periodontitis subjects. Compared with periodontitis group, mean DAQS score in participants with non-periodontitis was higher. After adjusting for all possible confounding factors, the results showed that high quality group of DAQS was related to the decreased risk of periodontitis [odds ratio (OR) = 0.80, 95% confidence interval (CI): 0.67–0.95, $P = 0.012$]. Subgroup analysis showed that the association between high quality group of DAQS and periodontitis was significant in participants without diabetes nor dyslipidemia (OR = 0.58, 95%CI: 0.39–0.87, $P = 0.009$).

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Conclusion: Based on data from nationally representative data from the US population, DAQS is found to be associated with periodontitis risk.

Introduction

Periodontitis is a chronic and common inflammatory disease that reportedly affects more than 40% of adults in the US.[1] Due to its high prevalence, periodontitis has been one of the important public health problems worldwide.[2] Periodontitis not only causes tooth loss and increases the risk of masticatory dysfunction, but also affects the patient's quality of life and general health.[3] Thus, it is very important and necessary to understand the factors related to periodontitis and to intervene as early as possible.

Oxidative stress and inflammation are considered to involve in the progression of periodontitis.[4] With an ability to remove free radicals and inhibit lipid peroxidation, dietary antioxidants have been reported to be associated with periodontitis.[5,6] In the study of Martinon P et al., they concluded that antioxidant effects of vitamins have beneficial effects on the prevention and treatment of periodontitis, such as vitamin A, B, C, calcium, zinc and polyphenols.[7] However, the effects of diet on health are influenced not only by individual nutrients, but also by the interactions of multiple nutrients.[8] Single nutrient has certain limitations in evaluating the total antioxidant capacity of diet.[9,10] The Dietary Antioxidant Quality Score (DAQS) summarizes certain dietary antioxidants and calculates a quantity score based on the dosage recommended by the FDA, which has been proposed to determine the overall impact of antioxidants on health outcomes.[11] A prospective cohort study assessed the independent relationship between overall dietary antioxidants intake and all-cause and cardiovascular disease (CVD) mortality, and showed that a higher DAQS was related to the decreased risk of all-cause and cause-specific mortality among adults with diabetes.[10] Nevertheless, as far as we know, evidence to date linking relation between DAQS and periodontitis is limited.

Herein, this study aimed at exploring the relationship between DAQS and periodontitis by using nationally representative data from the US population, followed by stratified specific analyses based on diabetes and dyslipidemia.

Materials and methods

Study population

For this cross-sectional study, data were retrieved from National Health and Nutrition Examination Surveys (NHANES) 2009—2010, 2011—2012 and 2013—2014. NHANES is cross-sectional sampling survey of a representative sample of non-institutionalized individuals in the US population, combining interviews, physical examinations and laboratory assessments.[12] We included 10,714 participants with periodontal examinations. Participants were excluded if meeting the following criteria: (1) edentulous (n = 2); (2) no complete dietary data (n = 618); (3) reported an implausible energy intake (<500 or >3500 kcal/day for women and <800 or >4000 kcal/day for men, n = 637). Finally, a total of 9457 participants were enrolled for further data analysis. Fig. 1 shows the flow of population selection. All patients have provided written informed consent prior to participation in NHANES. The study used publicly available data from NHANES, and the ethics committee of Peking University Shenzhen Hospital was exempt from ethical review.

Dietary antioxidant quality score

The DAQS was calculated by comparing the daily dietary intake of six micronutrients to the recommended daily intake (DRI), including vitamin A, vitamin C, vitamin E, selenium, magnesium and zinc.[10] For each antioxidant micronutrient, the DAQS was assigned as "0" if the intake was <2/3 of the DRI and "1" if the intake was ≥2/3 of the DRI. The scores for each micronutrient were summed, and the total score of the DAQS ranged from 0 to 6, with a higher score indicating greater the level of dietary antioxidants. In the present study, the DAQS was divided into three groups: low quality group (1—2 points), medium quality group (3—4 points) and high quality group (5—6 points). The United States Department of Agriculture (USDA) Food and Nutrient Database for Dietary Studies (FNDDS) was adopted to calculate the dietary antioxidant micronutrient and total energy intake values. The intake values for each micronutrient and total energy in this study were the sum of the intakes recorded on the first-24 h in the database and supplements.

Periodontitis assessment

The outcome was defined as periodontitis risk. Clinical examinations of periodontal and dental status were performed by dental examiners on all NHANES participants aged ≥30 years between 2009 and 2014. Periodontal status was divided into three groups: mild, moderate and severe. Mild periodontitis was defined as ≥ 2 interproximal sites with a clinical attachment loss (CAL) ≥ 3 mm, and ≥2 interproximal sites with a periodontal probing depth (PPD) ≥ 4 mm (not on the same tooth) or ≥ 1 interproximal site with PPD ≥5 mm. Moderate periodontitis was defined as ≥ 2 interproximal sites with a CAL ≥4 mm (not on the same tooth) or ≥ 2 interproximal sites with PPD ≥5 mm (not on the same tooth). Severe periodontitis was defined as ≥ 2 interproximal sites with a CAL ≥6 mm (not on the same

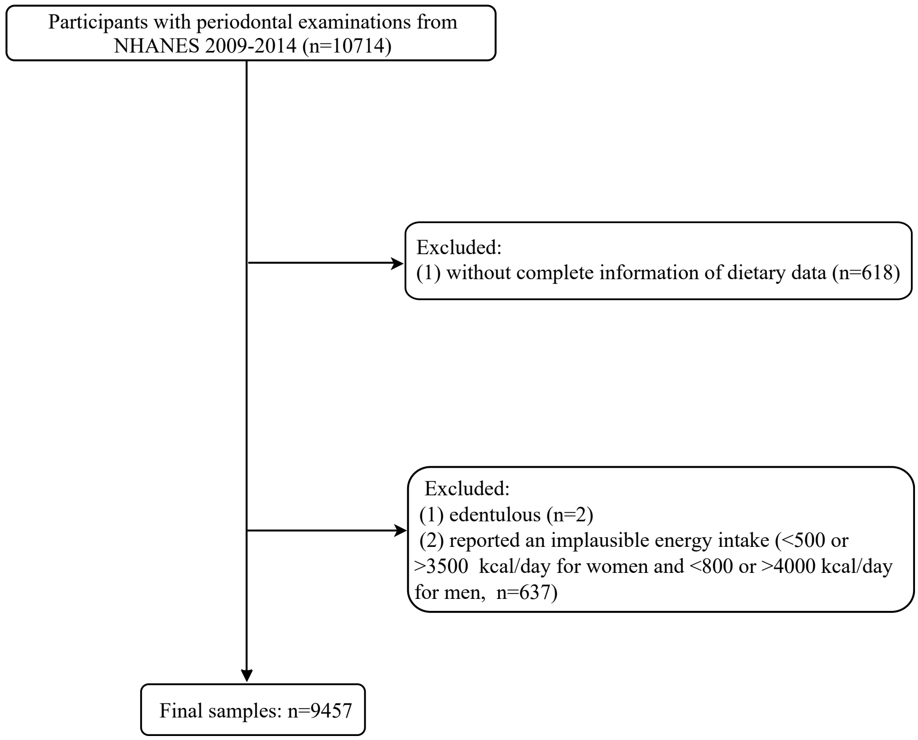

Figure 1 The flow of population selection.

tooth) or $\geq$ 1 interproximal site with PPD $\geq$5 mm (not on the same tooth).[13] For the present study, in order to reduce the bias risk from the potentially high prevalence of mild periodontitis in the population, we classified participants with mild or no periodontitis were classified into the reference group, and participants with moderate and severe periodontitis into the periodontitis group.[14]

Data collection

We also included some variables in the analysis were as follows: age, gender, race, education level, body mass index (BMI, kg/m^2), income, smoking status, alcohol intake, physical activity [metabolic equivalent (MET)·min/week], hypertension, diabetes, dyslipidemia, CVD, peri-implant, the number of teeth missing, periodontitis medication, total energy (kcal), vitamin A intakes (mcg), vitamin C (mg), vitamin E (mg), selenium (mcg), magnesium (mg) and zinc (mg).

Participants in the NHANES database reported the frequency and duration of vigorous/moderate work-related activities, walking or bicycling, and vigorous/moderate recreational activities.[15] MET is often used to describe the energy consumption while performing a specific activity, and physical activity is calculated as "MET $\times$ exercise time/week (min/week) of the corresponding activity". Physical activity was classified as three groups in this study: <450 MET· min/week, $\geq$450 MET· min/week and unknown.

Statistical analysis

Continuous variables were described as mean (standard error) [Mean (SE)], and categorical variables as the number cases and composition ratio n (%). We assessed differences in covariates between the periodontitis group and the reference group by using independent samples t-test for continuous variables and chi-square tests for categorical variables. Multiple interpolation methods were performed for missing variables, and sensitivity analysis was conducted regarding the data before and after interpolation (Supplemental Table 1).

The weighted univariate logistic regression analysis was constructed to screen the possible confounding factors (Supplemental Table 2). Three weighted logistic regression models were carried out to examine the association of DAQS and periodontitis. Model I was a crude model; Model II adjusted for age, gender and race; Model III adjusted for age, gender, race, education level, BMI, income, smoking status, physical activity, hypertension, diabetes, dyslipidemia, CVD and the number of teeth missing. Meanwhile, this study also investigated whether the effects of DAQS and periodontitis differed in different populations by grouping according to whether they had diabetes and dyslipidemia. Odds ratio (OR) and 95% confidence interval (CI) was estimated. $P < 0.05$ was considered as statistically significant. Python 3.9 was used for missing value processing and SAS 9.4 software (SAS Software Institute, Kerry, North Carolina, USA) for statistical analysis.

Results

Description of the study population

Table 1 shows the characteristics of 9457 participants and the differences between subjects with periodontitis

Table 1 Characteristics of the study population.

Variables	Total (n = 9457)	Mild or no periodontitis (n = 4506)	Moderate and severe periodontitis (n = 4951)	*P*
DAQS score, Mean (S.E)	3.97 (0.03)	4.08 (0.04)	3.82 (0.03)	<0.001
DAQS group, n (%)				<0.001
1—2	2066 (18.54)	852 (16.34)	1214 (21.26)	
3—4	3945 (39.71)	1800 (38.53)	2145 (41.17)	
5—6	3446 (41.74)	1854 (45.13)	1592 (37.57)	
Age, years, Mean (S.E)	51.30 (0.28)	47.91 (0.32)	55.49 (0.35)	<0.001
Gender, n (%)				<0.001
Male	4517 (47.15)	1717 (40.16)	2800 (55.77)	
Female	4940 (52.85)	2789 (59.84)	2151 (44.23)	
Race, n (%)				<0.001
Mexican American	1343 (7.90)	486 (5.99)	857 (10.26)	
Other Hispanic	944 (5.38)	440 (5.15)	504 (5.66)	
Non-Hispanic White	4188 (69.23)	2267 (74.38)	1921 (62.87)	
Non-Hispanic Black	1922 (10.38)	774 (8.21)	1148 (13.06)	
Other Race - Including Multi-Racial	1060 (7.12)	539 (6.28)	521 (8.15)	
Education level, n (%)				<0.001
Less than 9th grade	897 (4.88)	225 (2.60)	672 (7.70)	
9-11th grade (Includes 12th grade with no diploma)	1229 (9.71)	407 (6.69)	822 (13.43)	
High school graduate/GED or equivalent	2031 (20.64)	829 (17.19)	1202 (24.89)	
Some college or AA degree	2698 (30.20)	1389 (30.37)	1309 (30.00)	
College graduate or above	2602 (34.57)	1656 (43.15)	946 (23.98)	
BMI, kg/m^2, Mean (S.E)	29.18 (0.12)	28.92 (0.15)	29.49 (0.18)	0.018
Income, n (%)				<0.001
<$20000	1818 (12.61)	627 (9.02)	1191 (17.03)	
≥$20000	7639 (87.39)	3879 (90.98)	3760 (82.97)	
Smoking status, n (%)				<0.001
No	5334 (56.06)	2941 (63.91)	2393 (46.38)	
Yes	4123 (43.94)	1565 (36.09)	2558 (53.62)	
Alcohol intake, n (%)				0.183
No	2570 (20.98)	1180 (20.25)	1390 (21.88)	
Occasionally	3891 (40.25)	1883 (39.64)	2008 (41.01)	
Frequently	2996 (38.77)	1443 (40.11)	1553 (37.12)	
Physical activity, n (%)				<0.001
<450 MET· min/week	1044 (10.76)	520 (11.30)	524 (10.09)	
≥450 MET· min/week	6017 (67.09)	2975 (69.29)	3042 (64.38)	
Unknown	2396 (22.16)	1011 (19.42)	1385 (25.54)	
Hypertension, n (%)				<0.001
No	4965 (56.36)	2765 (63.33)	2200 (47.76)	
Yes	4492 (43.64)	1741 (36.67)	2751 (52.24)	
Diabetes, n (%)				<0.001
No	7643 (85.52)	3898 (89.59)	3745 (80.49)	
Yes	1814 (14.48)	608 (10.41)	1206 (19.51)	
Dyslipidemia, n (%)				<0.001
No	2165 (22.42)	1202 (25.13)	963 (19.07)	
Yes	7292 (77.58)	3304 (74.87)	3988 (80.93)	
CVD, n (%)				<0.001
No	7605 (82.94)	3864 (87.51)	3741 (77.29)	
Yes	1852 (17.06)	642 (12.49)	1210 (22.71)	
Peri-implant, n (%)				0.109
No	9204 (96.89)	4357 (96.51)	4847 (97.37)	
Yes	253 (3.11)	149 (3.49)	104 (2.63)	
The number of teeth missing, n (%)				<0.001
≤5	6538 (76.89)	3749 (88.19)	2789 (62.95)	
>5	2919 (23.11)	757 (11.81)	2162 (37.05)	

(*continued on next page*)

Table 1 (*continued*)

Variables	Total (n = 9457)	Mild or no periodontitis (n = 4506)	Moderate and severe periodontitis (n = 4951)	*P*
Periodontitis medication, n (%)				0.122
No	9203 (97.07)	4372 (96.75)	4831 (97.47)	
Yes	254 (2.93)	134 (3.25)	120 (2.53)	
Total energy, kcal, Mean (S.E)	2033.40 (10.60)	2039.63 (14.20)	2025.71 (15.04)	0.494
Vitamin A intake, mcg, Mean (S.E)	656.65 (18.88)	667.43 (13.24)	643.34 (43.36)	0.623
Vitamin E intake, mg, Mean (S.E)	9.38 (0.13)	9.84 (0.22)	8.82 (0.20)	0.004
Vitamin C intake, mg, Mean (S.E)	175.89 (5.65)	177.24 (6.39)	174.23 (9.86)	0.799
Zinc intake, mg, Mean (S.E)	15.71 (0.20)	15.74 (0.21)	15.67 (0.32)	0.850
Magnesium intake, mg, Mean (S.E)	338.11 (3.24)	343.35 (4.29)	331.66 (4.84)	0.079
Selenium intake, mcg, Mean (S.E)	134.26 (3.90)	133.31 (4.80)	135.43 (6.65)	0.801

DAQS, dietary antioxidant quality score; GED, general educational development; AA, associate of arts; BMI, body mass index; CVD, cardiovascular disease; SE, standard error.

(n = 4951) and non-periodontitis (n = 4506). Among all participants, the mean age was 51.30 years, 52.85% were females, 43.64% had hypertension, 14.48% had diabetes, 77.58% had dyslipidemia and 17.06% had CVD. Additionally, the result also indicated that higher mean age and BMI in the periodontitis group. Compared with the periodontitis group, there were higher mean DAQS score and Vitamin E intake in the non-periodontitis.

Association between dietary antioxidant quality score and periodontitis

Table 2 shows the results of association analysis between DAQS and periodontitis. When using DAQS as a continuous variable, in this crude model, we observed a negative association between DAQS and periodontitis (OR = 0.89, 95% CI: 0.86–0.93, $P < 0.001$). After adjusting age, gender and race, DAQS was associated with periodontitis (OR = 0.88, 95%CI: 0.84–0.91, $P < 0.001$). After further adjusting all possible confounding factors, the relationship of DAQS and periodontitis remained (OR = 0.95, 95%CI: 0.90–0.99, $P = 0.023$). Our study also divided DAQS into three groups: low quality group, medium quality group and high quality group. Compared with low quality group of DAQS, high quality group of DAQS was found to be related to the decreased risk of periodontitis in the fully adjusted model (OR = 0.80, 95%CI: 0.67–0.95, $P = 0.012$). However, after adjusting all possible confounding factors, the relationship between medium quality group of DAQS and periodontitis was not significant ($P = 0.108$).

Subgroup analyses

Table 3 displays the results of subgroup analyses stratified by diabetes and dyslipidemia.

All included participants were divided into four group: subgroup I: participants without diabetes nor dyslipidemia; subgroup II: participants with diabetes and without dyslipidemia; subgroup III: participants without diabetes and with dyslipidemia; subgroup IV: participants with diabetes and dyslipidemia. For participants without diabetes nor dyslipidemia, high quality group of DAQS was associated with periodontitis (OR = 0.58, 95%CI: 0.39–0.87, $P = 0.009$). Nevertheless, we also found that the association between DAQS and periodontitis was not significant in subgroup II, subgroup III and subgroup IV.

Table 2 The association of DAQS and periodontitis.

Variables	Model I		Model II		Model III	
	OR (95%CI)	*P*	OR (95%CI)	*P*	OR (95%CI)	*P*
DAQS score	0.89 (0.86–0.93)	<0.001	0.88 (0.84–0.91)	<0.001	0.95 (0.90–0.99)	0.023
DAQS group						
1-2	Ref		Ref		Ref	
3-4	0.82 (0.70–0.96)	0.013	0.76 (0.64–0.90)	0.002	0.87 (0.73–1.03)	0.108
5-6	0.64 (0.55–0.75)	<0.001	0.59 (0.51–0.70)	<0.001	0.80 (0.67–0.95)	0.012

DAQS, dietary antioxidant quality score; OR, odds ratio; CI, confidence interval; Ref, reference.
Model I did not adjust any variables.
Model II adjusted age, gender and race.
Model III adjusted age, gender, race, education level, body mass index, income, smoking status, physical activity, hypertension, diabetes, dyslipidemia, cardiovascular disease and the number of teeth missing.

Table 3 Subgroup analyses based on diabetes and hyperlipidemia.

Subgroups	Sample size	OR (95%CI)	*P*
Subgroup I: Diabetes = No & Dyslipidemia = No			
DAQS score		0.88 (0.80–0.97)	0.011
DAQS group			
1-2	n = 461	Ref	
3-4	n = 797	0.82 (0.60–1.12)	0.205
5-6	n = 735	0.58 (0.39–0.87)	0.009
Subgroup II: Diabetes = Yes & Dyslipidemia = No			
DAQS score		0.87 (0.65–1.17)	0.357
DAQS group			
1-2	n = 38	Ref	
3-4	n = 75	1.22 (0.34–4.33)	0.754
5-6	n = 59	1.19 (0.38–3.71)	0.760
Subgroup III: Diabetes = No & Dyslipidemia = Yes			
DAQS score		0.98 (0.91–1.04)	0.439
DAQS group			
1-2	n = 1177	Ref	
3-4	n = 2371	0.87 (0.70–1.09)	0.217
5-6	n = 2102	0.88 (0.69–1.13)	0.304
Subgroup IV: Diabetes = Yes & Dyslipidemia = Yes			
DAQS score		0.95 (0.87–1.05)	0.349
DAQS group			
1-2	n = 390	Ref	
3-4	n = 702	0.99 (0.67–1.46)	0.940
5-6	n = 550	0.85 (0.58–1.25)	0.390

DAQS, dietary antioxidant quality score; OR, odds ratio; CI, confidence interval; Ref, reference.
Adjusted age, gender, race, education level, body mass index, income, smoking status, physical activity, hypertension, cardiovascular disease and the number of teeth missing.

Discussion

Overall, through the secondary analysis of the national representative NHANES data, this study found that DAQS was associated with periodontitis. Subgroup analyses suggested an association between DAQS and periodontitis among participants without diabetes or dyslipidemia.

Periodontitis is considered a chronic inflammatory disease that could cause a dysregulated inflammatory/immune response in the host.[16] Dietary antioxidants are thought to play an important role in periodontal health. A mini review elaborated the relationship between periodontal disease and vitamin A, C, E, folic acid, and calcium deficiency.[17] A recent cross-sectional study involving 5145 participants reported a non-linear relationship between dietary vitamin C intake and the likelihood of periodontitis,[6] which may be related to the role of vitamin C in maintaining and repairing healthy connective tissue and its antioxidant properties.[18] Magnesium is an essential nutrient for various biochemical reactions in the human body.[19] Several studies have shown that hypomagnesemia may lead to a variety of chronic inflammatory diseases.[19,20] Li XY et al., indicated that a higher dietary magnesium intake and a lower prevalence of periodontitis was linked after adjusting for gender, age, race, BMI, poverty, alcohol consumption, diabetes and smoking status.[21] It must be emphasized that previous studies only focused on the relationship of single antioxidants and periodontitis, ignoring the potential correlation between different antioxidants.[22] The foods that people eat often contain complex antioxidants, not just a single antioxidant. Therefore, it is important to assess the effects of overall diet in relation to periodontitis.

In recent years, DAQS has been evaluated and proven to be one of the indicators of diet quality.[23] The DAQS consists of the following six micronutrients: vitamin A, vitamin C, vitamin E, selenium, magnesium and zinc. A higher score means a higher the level of dietary antioxidants. Previous studies have evaluated the role of DAQS in several chronic diseases, such as *Helicobacter pylori* infection,[24] metabolic syndrome,[25] and cardiovascular fitness.[26] In this present study, the results implied that after adjusted age, gender, race, education level, BMI, income, smoking status, physical activity, hypertension, diabetes, dyslipidemia, CVD and the number of teeth missing, high DAQS may be associated with a reduced risk of periodontitis (OR = 0.80, 95%CI: 0.67–0.95). In other words, high level in antioxidants might reduce gingival inflammation and protect against the risk of periodontitis. To our knowledge, this is the first study to report the association between DAQS and periodontitis. It further provides evidence that moderate high intake of antioxidants may contribute to periodontal health. In addition, by stratified specific analyses based on diabetes and dyslipidemia, we also observed that the relationship of DAQS and periodontitis was not significant in some participants (participants with diabetes and without dyslipidemia;

participants without diabetes and with dyslipidemia; participants with diabetes and dyslipidemia). The possible reasons: patients with diabetes or dyslipidemia have higher levels of inflammation, the role of nutrients is limited;[27,28] in addition, some hypoglycemic, lipid-lowering drugs may also affect the relationship between antioxidants and periodontitis. However, these findings still need to be confirmed in future studies.

Our study has several limitations. The cross-sectional design of the NHANES limits the causal association between DAQS and periodontitis. Additionally, in the NHANES database, dental examinations were performed in adults at least 30 years of age, which limited our assessment of the association between DAQS and periodontitis in the younger population. On the other hand, 24-h dietary recall is an effective method of obtaining dietary intake, but subjective recall may lead to information bias. And the dietary data may not be representative of the participants' long-term eating patterns. Future prospective studies are needed to continue investigating the role of DAQS in periodontitis, as well as the mechanisms.

In conclusion, the present study suggests an association between DAQS and periodontitis in the United States adult population. This research provides evidence for the effect of enhanced antioxidant intake on periodontal health.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jds.2023.05.021.

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