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Nutrient Requirements and Optimal Nutrition

The Development and Validation of the Vegan/Vegetarian Athlete's Plate

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A B S T R A C T

Background: The Vegan/Vegetarian Athlete's Plate (Veg AP) is a modification of the Athlete's Plate designed to guide athletes about how to fuel adequately at various training loads on a vegetarian or vegan diet.
Objectives: The purpose of this study was to validate and determine the usefulness of the Veg AP among athletes of various competition levels.
Methods: Part 1 involved developing 120 vegetarian or vegan "plates" for athletes of different weights at different training loads. Nutrient content of these plates was measured and compared with sport nutrition and vegetarian nutrition guidelines. Part 2 entailed athletes watching a presentation about how to use the Veg AP and then having the athletes create their meals in a university dining hall in accordance with the Veg AP. The appropriateness of the plate was determined by a group of experts. A subset of these athletes participated in a focus group to further ascertain perceptions of the utility of the Veg AP.
Results: The Veg AP meets international sport nutrition guidelines for energy and macronutrient content. Micronutrient content of the Veg AP varies, and proper instruction about how best to build plant-based meals to include adequate iron, zinc, and vitamin B12 while avoiding excessive dietary fiber is warranted, particularly to support easier training loads and lighter weight categories. Athlete perception of the Veg AP was that it was educational and helpful for creating a vegetarian or vegan meal that sufficiently supports variable training loads, even for those experienced with vegetarian nutrition.
Conclusions: The Veg AP is a useful tool for teaching about vegetarian sport nutrition and providing practical guidance for athletes of a variety of sports and competition levels.

Keywords: exercise, physical activity, sports nutrition, sustainability, sustainable diets, vegetarian diet

Introduction

Global interest in plant-based eating has been growing, including among athletes. It is important to define terms when discussing different dietary patterns. "Plant-based" typically refers to eating patterns that prioritize protein sources from plants with minimal (if any) meat, fish, poultry, eggs, or dairy [1]. Vegetarian and vegan dietary patterns would be two examples of "plant-based" eating. Vegetarian, specifically lacto-ovo-vegetarian, diets exclude meat, fish, and poultry but permit inclusion of dairy (lacto) and eggs (ovo). Vegan diets exclude all animal-sourced foods. These distinctions are important, especially because protein derived from plants differs in amino acid composition and bioavailability from animal-sourced foods [2]. Therefore, proper education and training on how to appropriately fuel for exercise of various intensities on vegetarian and vegan diets are needed.

In 2026, 5% of the United States population surveyed ($n = 2096$) reported that they are vegetarian (including vegan), and 3% of the surveyed population were vegan [3]. Additionally, 67% of those

Abbreviations: AP, Athlete's Plate; MPS, muscle protein synthetic; PreS, knowledge survey about the Veg AP taken before watching a 30-min prerecorded presentation about the Veg AP; PostS, the same knowledge survey about the Veg AP taken after watching a 30-min prerecorded presentation about the Veg AP; RDN, registered dietitian nutritionist; Veg AP, Vegan/Vegetarian Athlete's Plate.

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surveyed reported that they sometimes, usually, or always eat vegetarian meals (including vegan meals). People choose to eat plant-based meals for a myriad of reasons; promoting physical health and environmental sustainability and holding ethical convictions about animal welfare are some of the main reasons reported [4].

Historically, there has been an assumption that consuming meat and dairy was required for optimal skeletal muscle growth and needed to support peak athletic performance. Well-designed studies in recent years, however, have challenged this notion, demonstrating that when individuals participate in resistance training and consume ample dietary protein (≥1.2 g/kg) and sufficient kilocalories, there are no significant differences in myofibrillar protein synthesis rates [5] or lean mass development when consuming protein in the amounts of 1.6 g/kg [6] or 1.8 g/kg [7] between those consuming vegan diets vs. omnivorous diets. Furthermore, to date, it appears that neither omnivorous nor vegetarian dietary patterns are consistently superior for promoting optimal athletic performance [8–11].

Visual food guides, such as the USDA's My Plate (the former tool for the Dietary Guidelines for Americans) [12], have been in existence for years and are useful for guiding the public about building well-balanced plates to support healthy lifestyles. Guides specific for athletes, such as The Athlete's Plate (AP) [13,14], have also been developed to assist athletes in understanding the unique fueling needs for higher energy expenditure from exercise. Although appropriately designed to reflect differential energetic and macronutrient needs by training intensity and volume (collectively contributing to "load"), these guides prominently feature red meat, fish, and poultry as main sources of dietary protein. Someone not well-versed in vegetarian nutrition may struggle to modify food consumption in a way that still meets nutrient needs. To help address this need, the VegPlate for Sports [15] was recently published to guide sport dietitians as they work with vegetarian and vegan athletes. Although a useful tool for professionals to guide their clients, the VegPlate for Sports does not provide visual guides that reflect varied amounts of different food groups, nor does it account for different training loads. Therefore, the purpose of this study was to develop, validate, and evaluate the usefulness of the Vegan/Vegetarian AP (Veg AP), which is an extension of the original AP (Figure 1), in a group of vegan, vegetarian, and omnivorous athletes using the AP Nutrition Education Program in a university dining hall with a sequential explanatory mixed-methods design.

Methods

This study was approved by the Institutional Review Board of the University of Colorado Colorado Springs (Applicable FWA #: 00002481) and complies with the Declaration of Helsinki. Data were collected in April and October 2021 on a university campus. This was a mixed-methods study with two main parts. The objective of the first part of the study was to determine whether the Veg AP meets international and vegetarian sports nutrition guidelines for easy, moderate, and hard training loads. The objective of the second part of this study was to determine whether the Veg AP is understandable and useful for athletes in constructing a nutritious vegan or vegetarian meal appropriate for their training load.

Part 1 evaluation of the Veg AP appropriateness compared with sport & vegetarian nutrition guidelines: quantitative portion: To determine whether the Veg AP meets international and vegetarian sports nutrition guidelines for easy, moderate, and hard training loads, eight graduate students in sports nutrition [four registered dietitian nutritionists (RDNs), four non-RDNs] designed 120 meals based on these plates (Figure 2). The meals were entered into Elizabeth Stewart Hands and Associates (ESHA) Food Processor SQL version 11.1 to be analyzed for nutrition content, and these values were compared with established sports nutrition guidelines [16]. In line with the original AP [13], carbohydrate needs were defined as follows: easy (4 g/kg/d), moderate (6 g/kg/d), and hard (8 g/kg/d). Training load is conceptualized as the product of training intensity and training volume [17]. Training load categories of easy, moderate, and hard and related carbohydrate periodization are commonly used in sports. Daily protein needs were set at 2.0 g/kg, which is the upper end of current internationally agreed on recommendations for athletes (1.2–2.0 g/kg/d according to the American College of Sports Medicine, the Academy of Nutrition and Dietetics, and Dietitians of Canada or 1.4–2.0 g/kg/d according to the International Society of Sports Nutrition) [16,18]. Because plant proteins typically have lower bioavailability than animal-sourced protein [2] and some work suggests people who obtain most or all of their protein from plant sources may need slightly more protein than omnivores [19], we conservatively chose this amount to ensure that protein would be sufficient to support the training needs of the athletes, even if a fully vegan diet was followed. See Table 1 for nutrient criteria by weight category. Meal plans were for 60-kg and 75-kg athletes, with each weight category receiving 30 vegetarian and 30 vegan meal plans (10 easy, 10 moderate, and 10 hard training meals per dietary pattern). Criteria for nutritional adequacy were based on the assumption that athletes would consume 77% of their total daily kilocalories during meals, with the remaining energy consumed through snacks [20]. Statistical analyses included 1-sample *t* tests for criterion values, 1-sample

FIGURE 1. The Vegan/Vegetarian Athlete's Plate featuring plates to support easy, moderate, and heavy training loads. Tbsp, tablespoon.

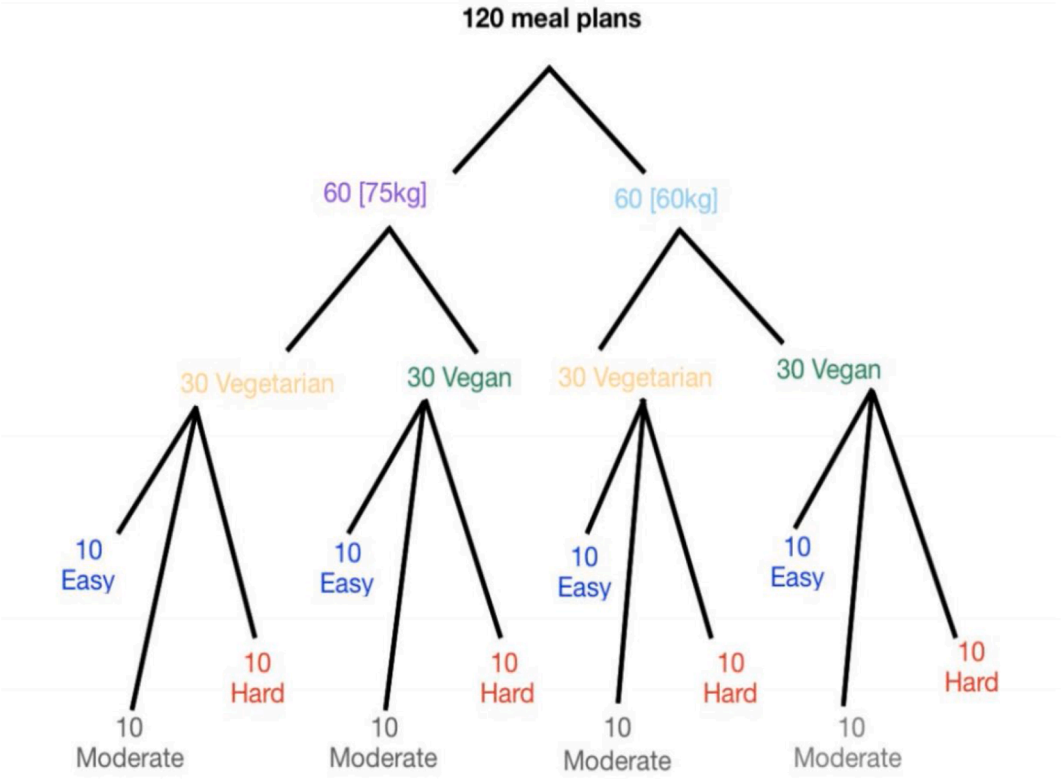

FIGURE 2. Meal plan distribution by diet, training load, and the weight category.

TABLE 1
Nutrient criteria by training load (100%/77% daily target)

Nutrient	Easy	Moderate	Hard
Kilocalories (kcal/kg)	30/23	45/35	55/42
Carbohydrate (g/kg)	4/3.1	6/4.6	8/6.1
Fat (g/kg)	1/0.8	1.5/1.2	2/1.5
Protein (g/kg)	2/1.5	2/1.5	2/1.5
Fiber (g/1000 kcal)	14/10.8	14/10.8	14/10.8
Vitamin B12 (μg)	6/4.6	6/4.6	6/4.6
Calcium (mg)	1000/770	1000/770	1000/770
Iron (mg)	Males: 14/10.8	Males: 14/10.8	Males: 14/10.8
	Females: 32/24.6	Females: 32/24.6	Females: 32/24.6
Zinc (mg)	Males: 16.5/12.7	Males: 16.5/12.7	Males: 16.5/12.7
	Females: 12/9.2	Females: 12/9.2	Females: 12/9.2

TABLE 2
Participant characteristics

Variable	Participants	*N*
Mean age (y, SD)	22.8 (5)	17
Sex	Males	13
	Females	4
Sports	Baseball	12
	Climbing	2
	Lacrosse	1
	Triathlon	1
	Soccer	1
Level of competition	Collegiate (Division II)	13
	Recreational	3
	Regional elite	1
Diet preference	Omnivore	12
	Vegetarian/vegan	2
	Other	3
Vegetarian/vegan experience	Experienced	7
	Inexperienced	10

Wilcoxon rank tests, and a factorial analysis based on RDN status, diet pattern, training load, and meal (breakfast, lunch, or dinner).

Part 2 knowledge survey: assessing usefulness of the Veg AP: quantitative portion: To determine whether the Veg AP is useful as an education tool for athletes to construct a nutritious vegan or vegetarian meal appropriate to their training load, athletes used the Veg APs to help them build their own meals in the dining hall, and these plates were evaluated for adequacy compared with established sport nutrition guidelines (Table 1). Inclusion criteria for athletes included exercising >5 h/wk and being interested in learning how to eat more plant-based. A convenience sample of participants was recruited from the local community and included collegiate (National Collegiate Athletic Association (NCAA) Division II), recreational, and regional elite athletes. Participant characteristics are shown in Table 2.

Athletes first completed a knowledge survey about the Veg AP [knowledge survey about the Veg AP taken before watching a 30-min prerecorded presentation about the Veg AP (PreS)]. Next, they viewed a 30-min prerecorded presentation about the Veg AP. The presentation covered terminology related to vegetarian and vegan nutrition; health, environmental, and potential performance benefits of eating a vegetarian or vegan diet; examples of meals for each plate [by weight category, diet (vegetarian vs. vegan), and training intensity]; and potential

nutrient deficiency risks. Immediately after viewing the presentation, athletes completed the same knowledge survey [the same knowledge survey about the Veg AP taken after watching a 30-min prerecorded presentation about the Veg AP (PostS)] to assess whether their understanding of the Veg AP had increased. Two additional questions were included in the post-survey. These questions asked athletes if they would be willing to eat a vegetarian or vegan meal once a week for the sake of the environment and if they found the Veg AP to be a useful tool.

After survey completion, athletes went to the university dining hall. The research team worked closely with the dining hall staff to ensure that there would be vegan and vegetarian meal options available. Athletes selected a card that indicated their training load (easy, moderate, or hard) and dietary preference (vegetarian or vegan) and then proceeded to take the food they wanted. Before eating, researchers weighed and photographed their trays of food. Photographs of plates were evaluated by the research team for nutritional adequacy to support the training load using a validated scale with a maximum point value of 13 for perfectly matching the criteria.

The scale was previously assessed for content validity by submitting it to a group (n =10) of sport dietitians known to the authors through membership in the dietetics practice group known as Sports, Cardiovascular, and Wellness Nutrition dietetics practice group. These dietitians were invited to complete a Qualtrics survey that had quantitative and qualitative questions to answer about the appropriateness of the tool. Based on feedback from these dietitians, the tool was modified and then considered to be valid. Statistical analysis included descriptive, Pearson product-moment correlations, dependent t tests to compare pre-survey/post-survey scores, and Mann–Whitney U tests to determine pre-survey/post-survey scores where comparisons were made, controlling for each athlete's experience level with vegetarian nutrition. The significance level was set as $P < 0.05$.

Part 3, focus group: assessing usefulness of the Veg AP: qualitative portion: A subset of athletes (n = 8) volunteered to participate in a focus group after their meal. The focus group used a semi-structured interview protocol designed with the stages of change (transtheoretical model) as the foundation of question formation. The interview structure was designed this way to minimize potential bias by having the researcher follow a structured set of questions while allowing the participants to share additional thoughts as they wished. The purpose of the focus group was to get in-depth feedback about the usefulness of the plates for constructing an appropriate meal to support the athlete's training for that day. Three focus groups were held 1 wk after the in-person portion of the intervention in the dining hall. Focus group duration ranged from 10 to 30 min, based on participants' level of engagement, were audio-recorded and transcribed verbatim for analysis. Data were collected over Zoom because of COVID-19 restrictions. The moderator for each group asked predetermined, open-ended questions about the Veg AP. Respondents stated their ID numbers for data to remain deidentified. After explaining the purpose of the current study and obtaining written consent, audio-recorded focus groups were conducted by a qualitative researcher who oversaw the evaluation study and did not participate in its implementation. The interview guide was created based on the socioecological model and the Theory of Reasoned Action and Planned Behavior (TRA-PB). The socioecological model is a framework that considers the complex interplay between individual, relationship, community, and societal factors [21]. The TRA-PB is a theory that suggests a person's health behavior is determined by their intention to perform a behavior. This intention can be predicted by the person's attitude toward the behavior and the subjective norms regarding the specific behavior [22]. Transcripts from focus groups were coded for themes and subthemes using an open-coding approach to develop a codebook with memoing (the process of making notes in the margins to use in the analytic process). Two researchers separately identified significant statements, then came together to compare and discuss discrepancies.

Results

Part 1 evaluation of the Veg AP compared with sport & vegetarian nutrition guidelines: Macronutrient, energy, and dietary fiber criteria for both weight categories and dietary patterns were met or exceeded for all training loads, with one exception (see Figure 3 for energy, macronutrients, and fiber). Mean protein content for the easy training vegetarian meal pattern for the 75-kg athlete was slightly lower than the targeted amount (1.3 g/kg vs. targeted goal 1.5 g/kg; $P < 0.05$). Mean fiber content of all plates exceeded the threshold of 14 g/1000 kcal. Fiber content ranged from 16 g/1000 kcal for the vegetarian 60 kg hard plate to ≤25 g/1000 kcal for the vegan 60 kg easy plate. Critical micronutrient content (vitamin B12, calcium, iron, and zinc) of the plates varied considerably (Figure 4). Calcium content of plates for both dietary patterns and weights at all training loads exceeded the established criterion, as did iron content based on the criterion for males (10.8 mg). However, the mean iron content of plates based on the criterion for females (24.6 mg) was significantly lower for eight of 12 (67%) plates ($P < 0.05$). Three of four (75%) hard training plates were sufficient for iron needs. Zinc content of all plates was below the established criterion for males (12.7 mg); 5/12 (42%) plates achieved zinc adequacy based on the female criterion (9.2 mg). The plates for which zinc adequacy was achieved based on the female criterion were moderate and hard training plates. Vitamin B12 content of eight of 12 (67%) plates was lower than recommended (4.6 μg); plates that achieved sufficiency were either moderate or hard training plates.

Part 2 assessing usefulness of the Veg AP: Results of the PreS and PostS knowledge scores are presented in Table 3. Knowledge scores improved significantly from PreS to PostS ($P < 0.001$), regardless of their prior experience with vegan/vegetarian nutrition. Athletes with prior experience began with higher levels of knowledge about vegan/vegetarian nutrition, and athletes without prior experience improved their scores more (Table 4). In addition, athletes experienced with vegetarian/vegan nutrition also built plates that more accurately matched guidelines from the Veg AP (Table 4). All athletes but one (94%, n = 16/17) reported that the Veg AP was useful. Fifty-nine percent (10 of 17) stated "yes" or "maybe" when asked, "Are you willing to choose a vegan/vegetarian day at least once a week to reduce your environmental impact and help mitigate climate change?"

Part 3 assessing usefulness of the Veg AP via focus groups: Themes, subthemes, representative quotes, and disciplinary concepts are presented in Table 5. Three main themes emerged, which were described as "an interesting new take," "I've chosen beans—now what?" and "it's a huge awareness piece."

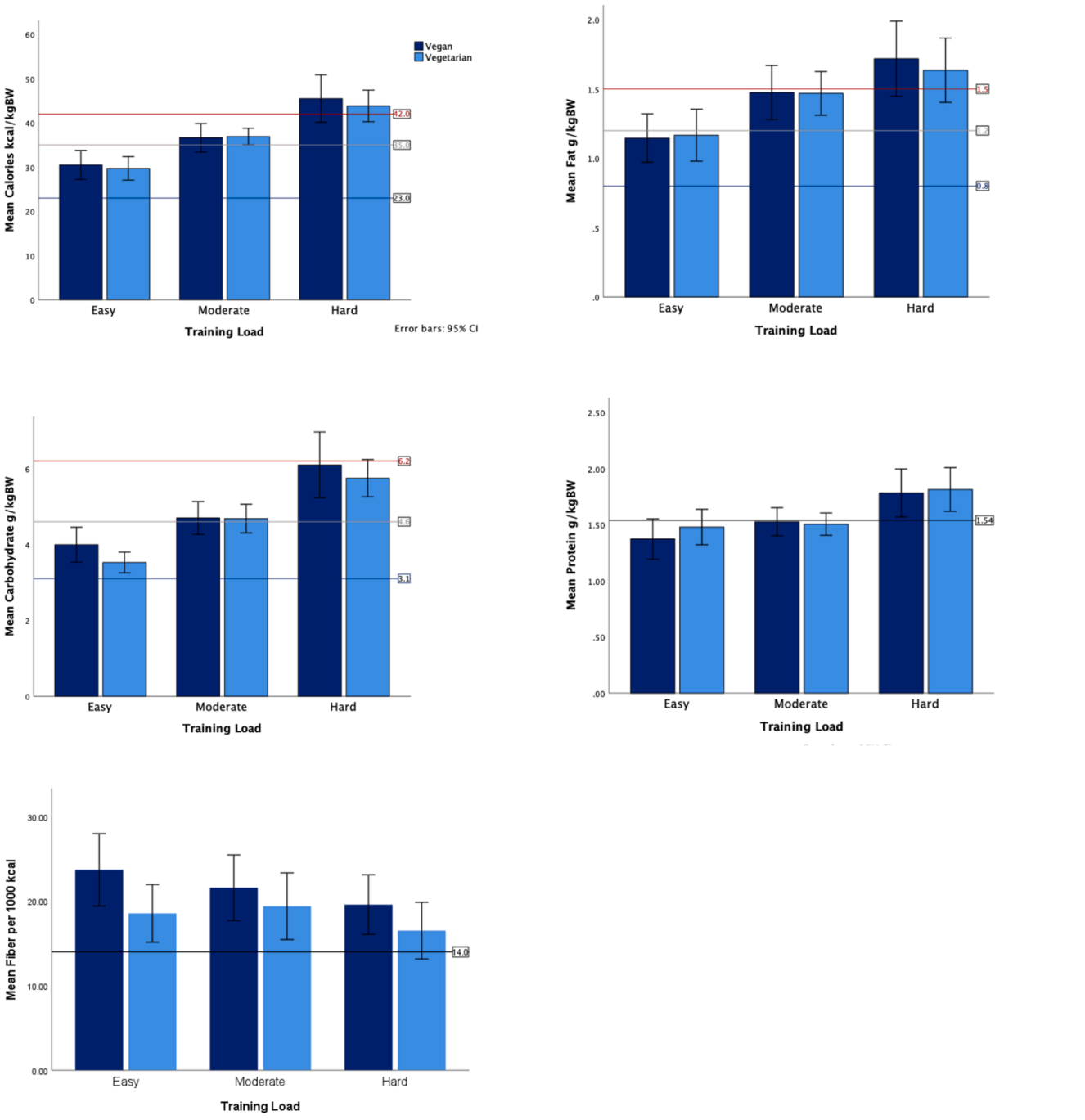

FIGURE 3. Median values for macronutrients and energy by diet, training load, and the weight category. Criteria values are indicated with horizontal lines and their values are noted. CI, confidence interval.

Discussion

Primary findings from this work include the following: *1*) validating that the Veg AP meets international sports nutrition guidelines for energy and macronutrient fueling for easy, moderate, and heavy training loads using either vegan or vegetarian meals; and *2*) determining that athletes were able to use the Veg AP to build appropriate meals to support their training load for the day, and finding out that the athletes perceive the plates to be helpful guides. The following discussion will address the distinctives of the Veg AP that differ from the original AP and then will address the three parts of the study as presented in the methods.

The purpose of this study was to create visual guides to help athletes eating vegetarian or vegan meals know how to appropriately fuel themselves at various training loads. To our knowledge, this study is novel for providing the first vegetarian and vegan visual guides based on training load for athletes. It is an adaptation of the original AP [13,14], which has been used internationally as well as further developed for different food cultures [23–25]. The vegetarian and vegan versions of the AP are timely and important, given the growing interest in

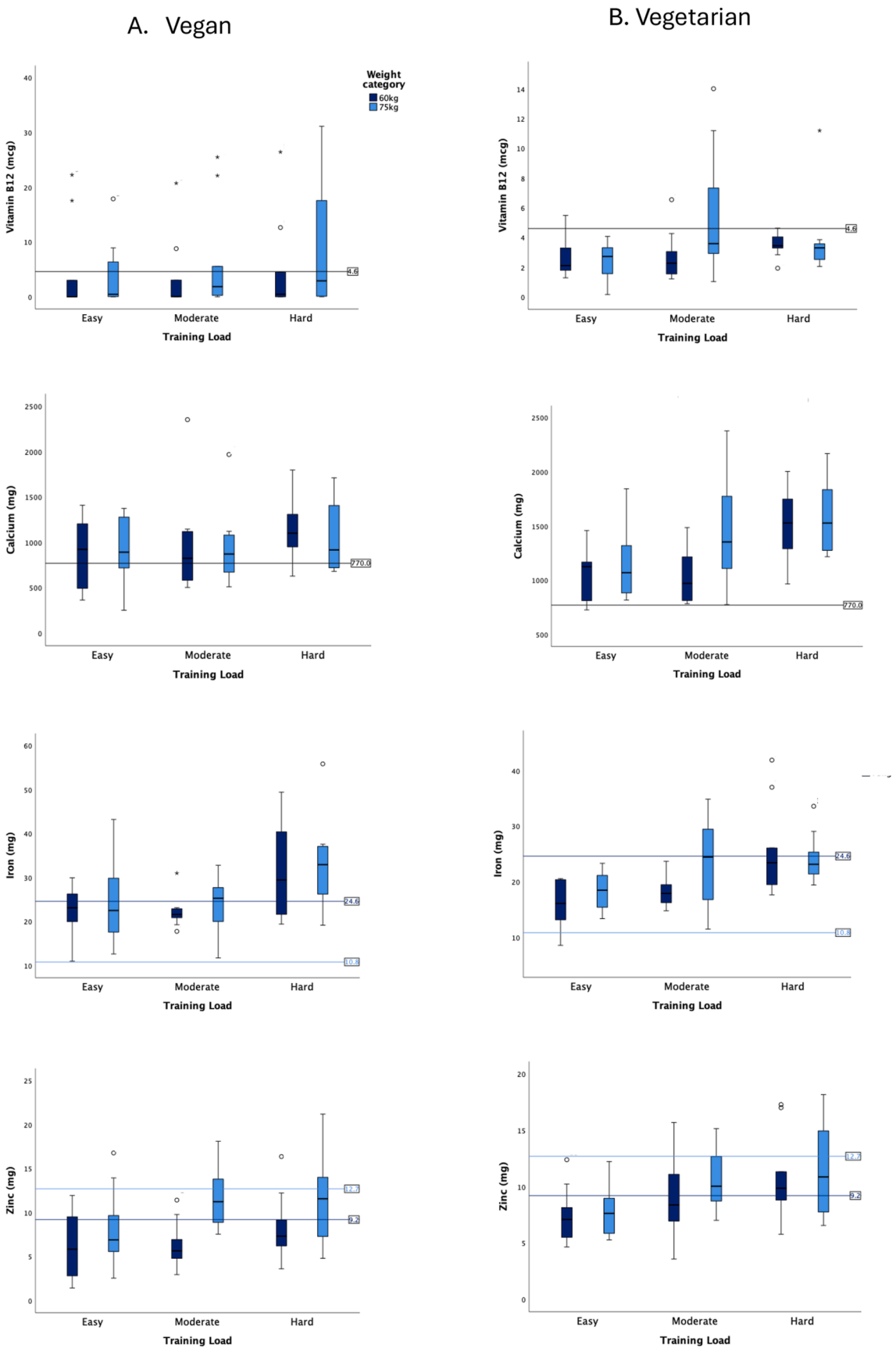

FIGURE 4. Boxplots for highlighted micronutrients with outliers indicated. (A) Data for vegan meals. (B) Data for vegetarian meals. Each boxplot represents data for 10 meal plans. Circles on the graph indicate mild outliers (between 1.5 and 3 times the IQR away from the edges of the box). Stars represent extreme outliers (farther than 3 times the IQR away from the box).

TABLE 3
Knowledge survey scores using the Veg AP pre-educational and post-educational presentation

	Mean ($n = 17$)	SD
Prepresentation survey score	9	5.1
Postpresentation survey score	15.7[1]	2.1

Abbreviation: Veg AP, Vegan/Vegetarian Athlete's Plate.
[1] $P < 0.001$.

TABLE 4
Comparison of survey score knowledge and Veg AP visual scores in athletes with and without experience in vegan/vegetarian diets

Variable	Experienced ($n = 7$)		Inexperienced ($n = 10$)	
	Mean	SD	Mean	SD
Prepresentation survey score	12.4[1]	3.9	6.6	4.5
Postpresentation survey score	17.3[2]	1.5	14.5	1.6
Veg AP visual evaluation of the plate score	8.9[1]	1.6	5.7	2.4

Abbreviation: Veg AP, Vegan/Vegetarian Athlete's Plate.
[1] Significantly higher baseline survey score and visual evaluation of the plate score among experienced athletes compared with inexperienced athletes, $P < 0.05$, Mann–Whitney U test.
[2] Significantly higher follow-up survey score among experienced athletes compared with inexperienced athletes, $P < 0.01$, Mann–Whitney U test.

plant-based nutrition among the general public and athletes. The Veg AP was developed not only to serve athletes who habitually consume vegetarian and vegan diets but also to assist all athletes and active individuals who are interested in eating plant-based meals periodically. These visual guides are also designed to help sport dietitians and other staff supporting athletes who are interested in plant-based eating.

Another objective of the creation of these plates was to visually display key aspects of a healthy vegetarian and vegan diet. For example, in addition to substituting sources of protein from meat to plants, the Veg AP features several additions unique from the original AP. Specifically, it highlights the importance of including fermented foods for gut health and for improving nutrient absorption, particularly from plants [26,27]. It also shows which micronutrients may warrant extra care to ensure they are consumed in sufficient quantities (and possibly to supplement) when eating vegetarian and vegan meals habitually.

To further improve the visuals of the plates, actual photographs of food are shown to showcase specific examples of appropriate types of foods for each training load, which contrasts with the original AP that used drawings. Words accompany the images to assist users who may be less familiar with the foods displayed. Foods represented are more culturally diverse than before (for example, masa, grits, and polenta have been added to the grains displayed). Dietary diversity is linked to the biodiversity of food production, evidenced especially in small- to mid-sized regenerative agricultural systems [28], thus positively impacting the environment [29]. Biodiversity in agriculture also promotes food security, nutrition, and health [30].

The Veg AP features other distinctive from the original plates as well. One such distinction relates to protein sources. Instead

TABLE 5
Themes from focus group ($n = 8$)

Theme 1: "An interesting new take"		
Subthemes	Representative quotes	Disciplinary concepts
Visuals	"a good take of this program was that it's very visual." "having been able to see those 3 plates and how your plate kind of gets adjusted" "so many different options"	Auditory + visual + kinesthetic = BEST environment for learning and education
Fermented foods	"I thought it was super interesting about adding fermented foods to your diet, so that you actually absorbed more because I had no idea."	Although you may "know something" or know about something, you may not know everything. There is always room for growth.
Inexperienced	"one thing that I learned that I didn't mention when you were talking earlier was just the knowledge on protein for vegan diet, just understanding where you can get your protein source. Because the misconception is that, that you will not get enough protein."	Awareness is the first step toward change Protein needs CAN be obtained through a balanced vegan or vegetarian diet
Theme 2: "I've chosen beans, so now what?"		
Subthemes	Representative quotes	Disciplinary concepts
Confusion	"time that I have in my day is like I might have a really hard workout you know," "then kind of sitting in the rest of the day, are very light activity, and if that makes that an easy day if I should decrease, you know, in taking calories" "should all 3 of your meals be proportioned as hard if you're having a hard day or just that 1 meal?"	Perspective through the eyes of the participants can help to make future education more user friendly Elicits questions to think about
Desire for more information	"I have a vegan eating plan I don't, I don't necessarily filter down more than that, so this is kind of an interesting opportunity for me to get a little bit more educated on diet."	Being vegan or vegetarian does not automatically make you "healthy." Knowledge and practice is key.
Theme 3: "It's a huge awareness piece"		
Subthemes	Representative quotes	Disciplinary concepts
Environment	"Everything's connected, and I think that's really hard for people when they just see like availability on the shelf because it's always going to be there" "I'm being more aware of and conscious with my grocery store visits and which places I'm ordering from online"	Having the smallest bit of awareness could kickstart a bigger change

of merely saying "soy" as an option for protein as in the original AP, a variety of types of soy foods are shown and listed, in addition to other plant sources of protein. Flavors coming from garlic, spices, and herbs are also depicted, which is an addition from the original AP. This recommendation is certainly not limited to those eating plant-based meals but is a wise way of increasing the healthfulness of any meal [31]. Like the original AP, the Veg AP encourages consumption of whole grains and more vegetables for easy and moderate training days but highlights refined grains for hard training days to help avoid excessive fiber intake that may lead to premature satiation.

Part 1: evaluation of the Veg AP appropriateness compared with sport & vegetarian nutrition guidelines: quantitative portion: An important part of assessing the adequacy of using these plates to guide athletes in preparing their meals is ensuring that the macronutrient and micronutrient content of the created meals meets sports nutrition guidelines. Ensuring nutrient bioavailability is part of this adequacy assessment, and protein is one nutrient for which bioavailability differs between plant and animal sources [32]. Protein quality is often a topic of special interest in discussions of vegetarian and vegan dietary adequacy for athletes, given the different digestibility and amino acid composition of the food sources of protein [33].

A common misconception is that athletes cannot consume sufficient protein on vegetarian or vegan diets to support optimal skeletal muscle adaptations to strenuous exercise. Isonitrogenous isolated animal-sourced protein powder supplements have been shown to elicit more robust acute muscle protein synthetic (MPS) responses compared with plant-sourced proteins at rest or after resistance exercise [34,35]. However, consuming plant-sourced protein enriched with leucine [35] or lysine [36] leads to similar MPS responses compared with ingesting the same amount of animal-sourced protein. Additionally, a recent study demonstrated that over 9 d, myofibrillar protein synthesis rates did not differ between healthy, physically active omnivores and vegans consuming a weight-maintenance diet that provided 1.1 to 1.2 g/kg/d of dietary protein and participating in resistance training (3 times over 9 d) [37]. A study on healthy older adults using deuterated water for 3 d also showed that daily myofibrillar protein synthesis rates did not differ between the group consuming a vegan diet compared with an omnivorous one; both dietary patterns provided 1.8 g/kg/d of protein and were energy matched, and both groups participated in resistance training [7].

In addition to examining muscle protein synthesis rates, researchers have investigated differences between plant- and animal-sourced protein for supporting lean mass changes over time in conjunction with resistance training. Meta-analyses have found no significant differences between groups supplementing with soy protein vs. animal-sourced protein in conjunction with resistance training for changes in lean body mass or strength development [38–40]. A recent intervention study showed that untrained young men who were habitual vegans or omnivores consuming protein in the amount of 1.6 g/kg/d and participating in resistance training increased lean mass, muscle fiber cross-sectional area, and strength similarly [6]. Protein consumption above 1.62 g/kg/d does not appear to lead to further increases in resistance exercise training-induced increases in lean mass among omnivorous populations [41], and the work by Hevia-Larraín et al. [6] suggests that this may be a similar threshold for vegans. Nonetheless, a recent large critical review by leading protein experts examined the proposition "Dietary protein benefits can be optimized equally and effectively with plant and animal proteins" and concluded that "Full acceptance of the proposition is not warranted based on available data, but existing evidence suggests plausibility" [42]. Given the totality of the data, it appears that the Veg AP provides sufficient protein to support athletes' needs and that athletes can confidently consume diets deriving most or all of their protein from plant sources.

This study highlighted that the Veg AP functions well as a visual guide for designing meals to meet energy and macronutrient needs of varying training loads for vegetarian and vegan meal plans for athletes of different weights. Although it certainly requires appropriate planning, this study has demonstrated that not only vegetarian but fully vegan diets can provide sufficient protein for athletes of different weights in line with recommendations (1.2–2.0 or 1.4–2.0 g/kg/d) [16,18]. We conservatively set the daily criterion for protein at 2.0 g/kg, based on sport nutrition guidelines [16,18] and the suggestion that vegetarians who consume minimal animal-sourced foods might benefit from a slightly higher recommended dietary allowance (RDA) for protein [19]. The only designed plate that fell slightly below the a priori criterion for protein was the vegetarian easy training plate for a 75 kg athlete, providing a mean of 98 g protein (1.3 g/kg) for 77% of the day's kcal values. This value would imply that the athlete would consume 1.6 g/kg of protein for the day overall when factoring in protein from snacks [20]. Because even fully vegan diets, providing 1.6 g/kg protein, comparably support lean mass development in conjunction with strength training [6], it is likely that even this plate would adequately support the athlete, even though it is below the conservatively set 2.0 g/kg/d threshold. To reiterate, 2.0 g/kg/d is the upper limit of protein recommended by multiple international sport nutrition groups. However, consumption of slightly lower (e.g., 1.6 g/kg/d) amounts of protein now appears to be sufficient for supporting muscle growth and remodeling, even among full vegans. It is noteworthy that a key benefit of the use of the Veg AP is that athletes should not need to calculate their actual macronutrient intake if they are building their meals following the visual guide of the Veg AP.

Carbohydrate content of all plates exceeded a priori thresholds. This is in line with previously published data about the carbohydrate content of vegetarian and vegan diets compared with omnivorous ones. Vegetarian and vegan diets typically are higher in carbohydrate content compared with omnivorous diets, both among athletes [11] and the general public [43]. In addition to higher total carbohydrate content, vegetarians and vegans typically consume more fiber compared with omnivores, both among athletes [44] and the general public [45]. Although this high carbohydrate content of vegetarian diets may facilitate glycogen synthesis and carbohydrate availability for exercise [46], attention must be given to avoiding excessive amounts of fiber at high training loads that may lead to premature satiation that could compromise energy intake [33].

Similarly, micronutrients that are frequently mentioned as being of potential concern for individuals following vegetarian and vegan diets include vitamin B12, zinc, iron, and calcium. Interestingly, although vegans typically consume less calcium compared with omnivores or vegetarians [47], calcium was

plentiful on all plates designed, including all vegan plates. This is in contrast to some data indicating that substitution of meat and dairy leads to reduced calcium in the diet [48] and highlights the feasibility of achieving sufficient calcium intake without consuming dairy.

Iron, zinc, and vitamin B12 adequacy of the plates designed by sport dietitians varied considerably depending on the training load and body weight category. Micronutrient sufficiency was easier to achieve when creating meals to support larger body mass (75 kg vs. 60 kg) and at heavier training loads (moderate and hard vs. easy), likely because of the larger amount of kcal needed and, consequently, more food opportunities to provide micronutrients. Additionally, iron thresholds were challenging to meet for the female criterion, whereas zinc thresholds were harder to meet for the male criterion.

The RDA for iron is 1.8 times higher for vegetarians and vegans than for omnivores because of the lower bioavailability of nonheme iron (found in plants) compared with heme iron (found exclusively in animal flesh) [49]. Furthermore, premenopausal females have an RDA for iron substantially higher than males (18 mg vs. 8 mg) because of menstrual cycle iron losses in blood. As such, female vegetarians and vegans require 32.4 mg of iron per day. Although the designed plates contain ample iron (mean iron content of all plates: 23.7 mg), this falls slightly short of the threshold criterion of 24.6 mg to provide 77% of the day's iron needs for females. It does, however, exceed the iron required for males on vegetarian and vegan diets (77% criterion: 10.8 mg). Because $\leq$60% of female athletes experience iron deficiency [50], consuming sufficient iron is not a challenge unique to vegetarian and vegan athletes, and supplementation is sometimes warranted.

Zinc bioavailability is also lower on vegetarian and vegan diets because of the greater presence of phytates and fiber [49]. Additionally, some of the richest sources of zinc are oysters and red meat. The zinc content of the designed plates fell short of the criterion for zinc for males at every training load; the criterion for zinc for females also was not met on the plates for lighter athletes (60 kg) and at easy training for heavier athletes (75 kg). This is likely due to the smaller amount of food on these plates. This highlights the importance of educating athletes about zinc-rich plant-sourced foods, including nuts and seeds as well as fortified foods (such as breakfast cereal) to help them achieve sufficient zinc intake, even on a more limited calorie budget. Although currently it does not appear that supplementation with trace minerals (besides potentially iron) would improve athletic performance [51], ensuring adequacy for overall health is still important.

As vitamin B12 is exclusively found in animal-sourced foods and fortified foods, it is often recommended that those following vegan diets consume a vitamin B12 supplement if they are not regularly consuming fortified foods [52]. Only 4 of the 12 plates met the vitamin B12 criterion, for either moderate or hard training, which require more kilocalories for fueling and thus provide more opportunities for consuming micronutrients. Accordingly, we affirm the wisdom in recommending a vitamin B12 supplement for most athletes on fully vegan diets [53]. It is noteworthy, however, that 3 of the 4 plates achieving sufficient vitamin B12 intake were vegan ones, including the vegan plate for a 60-kg athlete (hard training).

In addition to ensuring that sufficient amounts of the micronutrients and macronutrients are represented on the Veg APs, ensuring that fiber is not excessive was another key point for validating the Veg APs. Most people, [54] including athletes [55], do not consume sufficient amounts of dietary fiber, even though it is a key component of a healthy microbiome [18]. One benefit of fiber is its role in satiety and weight management. However, this same function is one that may become problematic for athletes who need to consume high-energy diets as it may lead to premature satiation before consuming adequate kilocalories [16]. The fiber content of each designed plate exceeded the criterion threshold (14 g/1000 kcal) [56], which could pose gastrointestinal challenges for athletes if meals and snacks provided pretraining or competition are high in fiber and could lead to difficulty with consuming the volume of food needed to achieve energetic goals. To address this, it is important to educate athletes about choosing lower fiber options for grains and produce on days with high training loads, as is shown visually on the hard training plate visual guide (i.e. "grains" instead of "whole grains" are advised). The high fiber content of all plates in this study is in contrast to the validation of the original AP [13], highlighting that many plant foods are rich in fiber. To help athletes moderate fiber intake along the training and competition plan, sport dietitians should teach about food selection and preparation (e.g., cooking vegetables for better digestibility) as well as getting athletes to adapt to higher fiber intakes at certain meals when training and competition cycles allow.

Overall, there was variability in the micronutrient content of the designed meal plans, which likely reflects the variable experience designing vegetarian and vegan meals for athletes of those who created the plates. This demonstrates the importance of training dietitians working with athletes about special considerations when athletes follow plant-predominant eating patterns [53]. Someone may be well-versed in sport nutrition guidelines or in vegetarian and vegan nutrition, but it is important to be equally well-trained in both areas when supporting athletes who want to eat in a vegetarian or vegan, or more generally, plant-based manner.

Part 2 knowledge survey: assessing usefulness of the Veg AP: quantitative portion: Phase 2 of the study also showed that when assessed quantitatively, the PreS and PostS scores showed that athletes need to be educated on the Veg AP to fully understand how to use the plates and all their features, even in athletes with previous experience in vegetarian/vegan nutrition. Like other studies, athletes with more experience with vegan/vegetarian nutrition showed a higher match of their plates with the recommendations [57]. Yang et al. [58] found that one of the main barriers to adopting plant-based diets is insufficient education on nutritional quality as well as limited availability of plant-based products. Arrazat et al. [59] also found that increasing the availability of vegan/vegetarian meals in the dining hall increased selection. This shows how educating athletes, exposing them to plant-based nutrition, and offering them alternative vegetarian and vegan foods and diets will help them make better Veg AP.

Part 3, focus group: assessing the usefulness of the Veg AP: qualitative portion: When assessing the usefulness of the AP through focus groups, three main themes emerged. The first theme was "An interesting new take" related to increased

awareness as well as an easy visual tool for education on the topic. Yang et al. [58] also found one of their main themes that emerged from their semi-structured interviews was "challenges in awareness and access," mainly linked to a lack of education and information. Thus, this fact highlights the need for better nutritional educational tools in vegetarian/vegan nutrition like the Veg AP. The second theme was "I've chosen beans, so now what?" which was linked to confusion as well as a desire to learn more. As with using any new tool, confusion can be part of the learning process, but the desire to learn more is a sign of motivation [60]. The third theme that emerged was "it's a huge awareness piece" mainly linked to the food impact on the environment, which has been found as a common motivator to adopt a more plant-based diet [58]. Athletes expressed interest in learning about the positive effect on the environment of following a plant-based diet and willingness to eat a vegetarian or vegan meal once a week for the sake of the climate. This is in line with a growing movement among athletes to change dietary patterns to eat more plant-based to mitigate climate change [15]. For example, in 2025, over 450 Olympians wrote an open letter to the International Olympic Committee, asking the incoming president "to make caring for our planet their top priority" [61]. In the general population, a study recently revisited the willingness to reduce meat intake for environmental causes and found that compared with 2016 [62], there was greater willingness to reduce meat intake, but major barriers remained present [63]. Taken together, education and accessible experiences and choices are critical to help athletes shift to more plant-based eating.

Our study has several strengths that set it apart. First, in addition to demonstrating that the Veg AP aligns with established sports nutrition guidelines, this study also highlights the usefulness of the plates in "real life" with athletes. Second, we assessed the Veg AP's utility both quantitatively and qualitatively through focus groups. Listening to the reflections of athletes yielded a richness that would have otherwise been missed from quantitative assessments of their plates alone. For example, we learned that even athletes experienced with vegetarian nutrition previously still learned about appropriate fueling for sport on a plant-based diet. Third, we included a diverse group of athletes (males and females, team sport athletes and individual sport athletes, at varying competition levels). Eliciting feedback from a broad group like this improves external validity because the Veg AP is designed to be used by athletes and their support staff at a variety of levels of competition and for all types of sports.

Challenges from our study were largely due to COVID-19-related restrictions. This hampered recruitment, necessitating three cohorts. All efforts were made to minimize bias and to ensure standardization between cohorts. The prerecorded educational presentation that athletes in all cohorts watched assisted with standardization. Pandemic-related modifications also led to a served rather than self-serve provision of food at the dining hall. Nonetheless, athletes were able to communicate how much different types of food they would like, and dining hall staff worked well with research study staff. Originally, the focus groups were going to meet in person, but this was changed to meeting online. However, the global community was accustomed to virtual meetings by necessity because of the pandemic, and recording the focus groups facilitated later transcription.

In conclusion, to our knowledge, the novelty and practical application of the Veg AP include being the first study to create visual vegetarian and vegan food guides for athletes, adjusted to training load. This tool has been validated by sport dietitians and aligns with international guidelines for sport nutrition and vegetarian/vegan nutrition. It is simple and easy to use for athletes, registered dietitians, and others supporting athletes interested in eating more plant-based.

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Author contributions

The authors' responsibilities were as follows – HML, NM: designed research; NM: conducted research and analyzed data; HML, ARC, NM: wrote the paper; HML: had primary responsibility for final content; and all authors: read and approved the final manuscript.

Conflict of interest

The authors report no conflicts of interest.

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Data availability

Data described in the manuscript, code book, and analytic code will be made available on request pending application and approval.

Declaration of Generative AI and AI-assisted technologies in the writing process

The authors declare that no generative AI or AI-assisted technologies were used in the writing of this manuscript.

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