Muscle Growth and Strength Development Following a 12-Week Resistance Training Program: a Comparison Between Consuming Soy and Whey Protein Supplements Matched for Leucine Content

by

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ABSTRACT

Sustainability, as it relates to nutrition, affects all aspects of food from systems-level production to consumption. Viability of local food systems in the southwest of the United States has been largely understudied. In order to address this gap in the literature, semi-structured interviews were conducted with 20 farmers in Arizona and New Mexico to determine best practices, challenges and barriers to farming. Interviews were recorded, transcribed, and coded for themes. Many trends were consistent with those reported elsewhere in the US, but the importance of water emerged, a unique need not explicitly noted in other regional studies.

Vegetarian diets are typically more sustainable than omnivorous ones due to using less environmental resources in the production of food. An important consideration with plant protein and vegetarian diets, however, is whether this would affect athletic performance. To examine this, 70 male and female endurance athletes were compared for maximal oxygen uptake (VO2 max), peak torque when doing leg extensions, and body composition. Vegetarians had higher VO2 max, but peak torque was not significantly different by diet. Omnivores had higher total body mass, lean body mass, and there was a trend for peak torque to be higher.

To investigate whether plant-protein can comparably support development of lean body mass and strength development in conjunction with strength training, 61 healthy young males and females began a 12-week training and protein supplementation study. While previous training studies have shown no differences for lean body mass or strength development when consuming either soy (plant) or whey (animal) protein supplements in very large amounts (>48 grams), when consuming around 15-20 grams, whey has

contributed to greater lean body mass accrual, although strength increases remain similar. The present study matched supplements by leucine content instead of by total protein amount since leucine has been shown to be a key stimulator of muscle protein synthesis and is more concentrated in animal protein. There were no significant differences between the whey or soy group for lean body mass or strength development, as assessed using isokinetic dynamometry doing leg extensions and flexions.

DEDICATION

I would like to dedicate this dissertation to my husband, Sean Lynch, for his incredibly patient support and care, particularly over the past three years. Thank you for encouraging me to pursue a career about which I am passionate, and for all of your selfless love in this process. I'd also like to thank my parents, Harold Netland, for showing me how to be an excellent scholar while keeping his relationship with Christ at the center of his life and always keeping time for his family, and Ruth Netland, for her hours of listening to my joys and struggles, praying for me, and always encouraging me.

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CHAPTER 1

INTRODUCTION

Sustainability, as described by the Food and Agriculture Organization of the United Nations, ensures "human rights and well-being without depleting or diminishing the capacity of the earth's ecosystems to support life, or at the expense of others' well-being" [1]. This broad definition reflects the importance and impact of considerations of sustainability across food systems, from production through to consumption, and including human health and performance outcomes. As such, as it relates to nutrition, food, and food systems, sustainability comprises issues of how to grow, produce, and deliver healthy food to consumers in the least environmentally destructive ways possible, while simultaneously ensuring livelihoods for those who work in the food system and optimizing health for consumers of food system products. A growing body of literature delineates the greatly varying environmental impacts of producing different types of food and the cumulative impact of varying dietary patterns [2-8]. Importantly, researchers increasingly include the dual consideration of health and sustainability outcomes of the food system in a variety of new venues, including, for example, athletic performance and sport. Cutting-edge research is now exploring what it might mean to incorporate more sustainable dietary practices into athletic settings, even at the elite level [9].

The reasons for consideration of sustainability in food are many. Resource requirements and waste products (including 'greenhouse gas' emissions) that in part make up the life cycle of food production, distribution, and consumption, represent vital intersections of decision-making related to optimizing human health while minimizing impact on fragile ecosystems. Studies employing life cycle impact assessments (LCA) bear this out. LCA systematically quantifies the toll of a given product from its origin to final disposal and includes all processes between such as growing, harvesting, transporting, processing, packaging, cooking, storage, and waste disposal [6]. Studies comparing effects of different dietary patterns on the environment often compare vegetarian and omnivorous diets, although several subcategories such as pescetarians or vegans may be considered as well.

LCA studies have shown that vegan diets impart the least environmental toll, followed by vegetarian diets, and that omnivorous dietary patterns are the most resource-intensive [3]. Specifically, land, energy, fertilizer, and pesticide use are more intensive for producing foods for omnivorous diets compared to vegetarian ones [4]. When looking at food items individually, production of animal products emits more greenhouse gases, and contributes more toward air acidification and freshwater eutrophication than growing plants for food [10]. Not all animal agriculture has the same environmental burden, however. Ruminants require exceptionally excessive energy inputs compared to energy output available, with lambs and beef cattle requiring 57 and 40 times the caloric input for the caloric output, respectively [5]. A study by Baroni further separated conventional agriculture from organic farming and showed that compared to conventional farming, organic farming reduced total environmental impact considerably [3]. The reduction in environmental burden in this study was seen for omnivorous, vegetarian, and vegan diets.

Considering nutrition from an ecological perspective further elucidates the issues and opportunities inherent in optimizing dietary patterns for both health and environmental reasons [11]. A number of studies have examined the intersection of human and environmental health and found that often what promotes human health is also environmentally advantageous. Soret and colleagues demonstrated that not only do vegetarian diets produce fewer greenhouse gas emissions (GHGEs), but vegetarians also have a lower hazard ratio for all-cause mortality [2]. Masset and colleagues found that foods with the highest negative environmental influence also tended to be lower in nutritional value [12]. They further demonstrated that one way of reducing diet-related GHGEs and simultaneously benefiting human health is to reduce caloric intake and increase percent of plant-based foods in the diet. Importantly, they noted that this can be a culturally acceptable approach among the population they surveyed [10]. Others have shown that adherence to a dietary pattern widely recommended in the prevention and management of hypertension, the DASH diet (dietary approaches to stop hypertension), has been shown to reduce GHGEs as well [13]. Further, Springmann and colleagues showed that switching to a more plant-based diet, while remaining within recommended dietary guidelines, could reduce GHGEs by 29-70% and mortality by 6-10% [14].

Large epidemiological studies such as the Adventist Health Studies and the EIPC-Oxford Vegetarian Study have focused on identifying differences between vegetarians and omnivores for a variety of health outcomes. Findings from a number of studies in this population show that vegetarians had lower rates of ischemic heart disease [15], all-cause mortality [16], risk of cataracts [17], obesity [18], and certain types of cancers [19]. Comparing vegetarians to more health-conscious omnivorous counterparts (instead of a broader sample of omnivores) mitigated some of these differences, however [20].

Given the environmental and human health benefits of plant-based diets, opportunities exist to explore how food systems that preference plant-food production can operate to ensure livelihoods in food systems, access to healthy foods, and incorporation of healthy and environmentally less impactful dietary patterns across populations of all types. Local food systems, or those in which foods are produced and sold in a smaller, regionally defined area, can play a valuable role in the delivery of fresh, nutrient-dense foods to local communities. Currently, local and regional food systems are a matter of considerable consumer and research interest, and many of the roles filled by local food systems are priority areas of interest for the United States Department of Agriculture (USDA). These roles include strengthening the rural economy, improving environmental sustainability, increasing access to healthy food, meeting consumer demand, and improving dietary patterns of communities [21].

In spite of the importance of local food systems, there are considerable obstacles and challenges for the actual operation of small-scale regional farms. Most farms in the U.S. are quite small, with most farmers having only 10-49 acres of farmland [22]. Additionally, revenue from farming provides less than 25% of income for over 70% of farmers, and the number of new farmers entering the profession is decreasing at an alarming rate [23]. This is especially troublesome given that the average age of principal farm operators is 58.3 years, and fewer than 16% of principal operators are 44 years old or younger [23].

Numerous studies already exist that define the challenges, barriers, and motivators for small, local farming in order to determine how best to support these valuable institutions. This is an issue not only within the U.S. but also internationally where many farmers have reported similar challenges to those noted domestically [24-26]. Typically studies assessing farming viability have been conducted regionally, given that climate and geography directly impact farming. In the United States, farming has been well-studied in California [27], Indiana [28], Maryland [29], New York [30-32], Pennsylvania [33], Colorado [34], and the northeast and southeast [35]. A strikingly understudied region, however, is the southwest of the United States. This is surprising since Yuma County in Arizona is the nation's third leading vegetable producer, and it provides 90% of the leafy greens for the U.S. between November and March [36].

Improving livelihoods and the resilience of local food systems can bolster access to healthy, and often, more plant-based foods. However, food systems concerns cannot end there. While broad dietary recommendations have consistently identified plant-based (but not necessarily vegetarian or vegan) diets as the most healthful, the application and impact of plant-based diets in some specialized populations remains understudied.

Sports nutrition focuses on optimized nutrient intake to support the highest levels of sports performance. As with any specialized diet, the efficacy of a vegetarian or vegan diet for adequately supporting high-level performance merits careful scrutiny, regardless of why an athlete chooses to follow such a diet. While nutrition is only one of many factors impacting sport performance, it is certainly important for optimizing energy availability during exercise, recovery from training and competition, enhancing immunity, and helping to regulate an appropriate body weight and composition. As such, most studies assessing the effect of switching to a vegetarian diet or to consuming plant-based protein supplements typically have focused on changes in one or more of these parameters. However, much of the research in this area suffers from important limitations. A number of papers published to date addressing adequacy of vegetarian diets for athletic performance have not actually been randomized controlled trials, but instead have provided recommendations based upon typical nutrient intake differences between vegetarian and omnivorous diets and how these could potentially impact performance [37-41]. As vegetarian diets are typically higher in carbohydrate and lower in protein than omnivorous patterns among the general population [42-44], it has been proposed that these differences could facilitate improved endurance exercise performance due to the higher carbohydrate content to help maximize glycogen storage and replenish depleted stores [45]. However, most studies to date have reported no differences in performance between vegetarian and omnivore athletes [46-49].

Other studies that intended to compare vegetarian and omnivore athletes actually randomized omnivores to adopt a vegetarian diet for the duration of the study and extrapolated conclusions to athletes who have adhered to a vegetarian diet long-term. Whether such differences would exist in long-term vegetarians compared to omnivores remains less studied, however.

Since muscle mass and strength are vital components affecting sports performance in many ways, research has focused upon efficacy of plant protein compared to animal protein, when consumed as a supplement in conjunction with strength training, to facilitate strength and lean body mass development. Although some studies providing protein supplements in exceptionally large amounts (48-104 g protein, in addition to protein in the diet) have found no differences in muscle growth and strength development between groups [50-52], others providing protein in smaller doses (about 20 g) have demonstrated a superior effect for whey protein or milk (animal-based proteins) over soy (a plant-based protein) [53, 54]. These studies have all matched protein sources nitrogenously, however, and mechanistic studies suggest that the essential amino acid leucine may be a key driver of muscle protein synthesis [55-58]. Since whey protein is more concentrated in leucine than soy protein, it is conceivable that these differential responses may be due to the lower stimulation of muscle protein synthesis, resulting in part from less ingestion of leucine. One training study to date has matched protein supplements by leucine content; however, this study compared a soy-dairy blend (made of 25% soy) with whey protein [59]. Since soy protein contributed relatively little to the total protein content of the supplement, both groups actually received similar amounts of protein . The whey group's supplement contained 2.31 grams of leucine, whereas the soy-dairy blend group had 2.00 grams of leucine, based upon previous work demonstrating the sufficiency of 2 grams of leucine for maximally stimulating muscle protein synthesis in healthy young men [60-62]. This study showed that the protein-blend group increased lean body mass and strength as much as the whey protein group; indeed, there was a trend for the protein-blend group to have slightly more lean body mass development.

Given the importance of considering health and sustainability from a systems perspective, we explored a number of vital aspects of the food system related to both environmental sustainability and optimized health and performance across three studies. Each study was meant to address a specific gap in the literature that touched upon health and sustainability simultaneously. In the first study, we conducted a survey of small-scale, mainly fruit-and-vegetable farmers in New Mexico and Arizona to better understand barriers and challenges to farming in the southwest, as well as best practices and motivators for being a farmer contributing to local food systems. We also evaluated issues related to availability and access of locally produced fruits and vegetables in these states.

In the second study, we compared 70 vegetarian and omnivorous endurance athletes cross-sectionally for cardiorespiratory fitness, strength, and body composition. This study expanded upon previous work [63], with a larger sample size, updated methodology such as using a dual x-ray absorptiometry (DXA) scan instead of skinfolds to determine body composition, and assessed maximal instead of submaximal oxygen uptake.

Finally, as no studies have compared a 100% plant-protein supplement with whey protein, matched by leucine content, we conducted a third study to address this question using healthy, young, untrained males and females. This study expands upon a study by Reidy and colleagues that compared a soy-dairy blend with similar leucine content to a whey protein supplement. Our study, however, included females along with males, as females are an understudied population in resistance training studies, as participants. This study sets a precedent for further work exploring other types of plant protein or protein blends, consumed either as whole foods or as protein supplements, and their effects on muscle growth compared to animal protein.

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CHAPTER 2

LITERATURE REVIEW

Introduction: Dietary patterns

Americans receive dietary information from a plethora of sources, both reputable and questionable. But a fundamental source of evidence-based scientific nutrition recommendations comes in the form of the Dietary Guidelines for Americans and its associated graphic, MyPlate, both of which are published jointly by the US Departments of Agriculture (USDA) and Health and Human Services (USDHHS) [64]. This continues a long tradition of government guidance dating to Dr. Wilbur Atwater, who published "Foods: Nutritive Value and Cost" in 1894 for USDA [65]. Since that time, official guidelines have evolved as the scope and depth of nutrition science grew. For example, in 1916 "Food for Young Children" was issued, which provided specific recommendations about amounts of foods from specific food groups to be served to young children [66], and in 1917 a guide called "How to Select Foods" was published to help families see what to purchase in order to meet these dietary and nutrient-based recommendations [67].

Several later historical events influenced guidelines throughout the twentieth century. The Great Depression of the 1930s was the impetus behind Hazel Stiebeling producing a guide for Americans for buying food at four different economic levels that would be nutritionally adequate [68], a format still used today for families planning food purchases on a budget [69]. World War II also had an impact. The "National Wartime Nutrition Guide," published in 1943, guided Americans on how to eat healthfully while wartime rations were in place [70]. The Basic Seven food groups were introduced at this time (green and yellow vegetables; oranges, tomatoes, and grapefruit; milk and milk products; meat, poultry, fish, or eggs; bread, flour, and cereals; and butter and fortified margarine). These recommendations were updated in 1956, and the "Basic Four" food groups (milk, meat, vegetable fruit, and bread cereal groups) became the basis of new recommendations [71]. Nineteen seventy-seven marked another turning point in dietary guideline development with the publication of the Dietary Goals for the United States, established by the U.S. Senate Select Committee on Nutrition and Human Needs [72]. To communicate these goals to the public, the government produced the Hassle-Free Guide to a Better Diet in 1979. Other predecessors to the current MyPlate model intended to communicate governmental dietary goals to the public included the 1984 Food Wheel: A Pattern for Dietary Choices, the 1992 Food Guide Pyramid, and the 2005 MyPyramid Food Guidance System [73].

Over the years, recommended dietary patterns have encouraged Americans to eat fruits and vegetables, grains, milk and meat products in various amounts. As a graphic, MyPlate currently displays an allotment of one-fourth of one's plate to "protein," in addition to one glass of milk [74]. The Healthy U.S.-Style Eating Pattern at the 2,000 kilocalorie level recommends 26 ounce-equivalents of meat per week and eight ounce-equivalents of seafood per week [64]. It also recommends consuming two cup-equivalents of fruit and two and one-half cup-equivalents of vegetables daily. Currently, about 80% of the U.S. population consumes fewer servings of fruits and vegetables than recommended, which is cause for considerable concern since higher consumption of fruits and vegetables is consistently linked with lower risks of developing chronic diseases [75, 76]. Conversely, about 80% of the US population meets or exceeds recommended intakes for protein [77].

Each of these government recommendations has been based on the most current science available at the time of publication, but they have not been issued without disagreement among top nutrition scientists [73]. Additionally, not all of the recommendations of the Advisory Council, an appointed group of nutrition experts who review the medical and scientific nutrition literature to develop the Dietary Guidelines, actually are included in the official Dietary Guidelines. For example, in the Scientific Report of the 2015 Dietary Guidelines Advisory Committee, the word “sustainability” is used in the text 63 times [77]. There are repeated strong statements from the Council about the human and environmental health benefits of eating a diet lower in animal-derived food than the current American diet, and warnings about the importance of developing more sustainable dietary patterns. However, the term “sustainability” is not used in the final version of the 2015-2020 Dietary Guidelines [64], nor is it featured anywhere on ChooseMyPlate.gov.

In spite of the politics that often influence developing and updating national dietary guidelines, recent consumer and research interest has centered on the intersection of meeting nutrition needs and sustainability implications of dietary choices. There is growing attention given to if and how less resource-intensive diets can improve health while reducing environmental impacts of the food system. This has led to renewed interest in alternative dietary and food system movements, such as local food systems and plant-based nutrition, including vegetarian and vegan nutrition. For example, small-scale local farms that focus on local food production and distribution have emerged as a viable way to help meet the needs of providing sufficient quantities of fruits and vegetables grown in sustainable ways to the public in order to help meet the Dietary Guidelines for produce consumption [28]. Local foods systems have been shown to contribute to economic growth in substantial ways [78], particularly in their own local economy [79]. Efforts are underway around the country to increase capacity for local fruit and vegetable production and distribution in part to address the lack of adequate consumption of fruits and vegetables [80]. Such efforts are accomplished, in part, by the work of University Cooperative Extension Educators [81]. The unique features of and opportunities presented by local farming and alternative food networks will be explored in the next section.

Local food/food systems sustainability

Among the various entities that contribute to local food systems, small farms, farmers' markets, community supported agriculture (CSA), and food hubs (also known as farmer cooperatives) have played critical roles [82]. Each of these models of food production and delivery represent areas of research related to their impact on supporting healthier, diversified, locally oriented food systems with social and economic implications, in addition to environmental implications.

Small farms Although historically there have been varying criteria for classifying farms as 'small-scale,' in 2013 the USDA Economic Research Service (USDA-ERS) provided definitions to help standardize terminology for research purposes. According to the USDA-ERS, "small family farms" maintain gross sales less than $250,000 annually and are not operated by a hired manager [83]. There are several types of small family farms, broken into two categories: rural-residence farms and intermediate family farms. Rural residence farms include retirement farms, where the main operator is retired, and residential/lifestyle farms, where the operator's main occupation is something other than farming. Intermediate family farms are considered farming occupation farms (that is, where the operator's primary occupation is farming), and are classified as either low-sales farms, which gross less than $100,000, or high-sales farms, which gross between $100,00 and $249,999 [83].

Eighty-eight percent of all U.S. farms are small family farms. These small farms are responsible for 58% of "direct-to-consumer" sales through, for example farmers' markets, CSAs, and roadside stands [84]. As such, they can serve an important role in supplying fruits and vegetables to help Americans meet the Dietary Guidelines goals for produce consumption.

Small, local farms are valuable not only for the fruits and vegetables that they produce, but also for other intangibles that they provide to their local communities and economies. Boys and Hughes have articulated the economic, social capital, and quality-of-life contributions of local food systems especially in relation to small-scale farms [78]. Part of the regional economic contribution of local farmers is that their expenditure patterns differ somewhat from farmers who grow for non-local markets. Jablonski and Schmidt report that local farmers rely more on local labor and allocate more of their expenditures locally compared to farmers who sell products outside of their own locale [79]. There is consensus, however, that data collection methods must be improved to further understand all of the community economic contributions of local foods systems on broader scales nationally [85-87].

While farm size alone does not necessarily dictate sustainable growing practices, Tavernier and Tolomeo have demonstrated that small-scale farmers are significantly more likely to favor sustainable agriculture than farmers on larger farms [88]. Sustainability, as defined by the Food and Agriculture Organization (FAO) means, "ensuring human rights and well-being without depleting or diminishing the capacity of the earth's ecosystems to support life, or at the expense of others' well-being" [1]. As such, there is a worker welfare element as well as an environmental one when considering sustainable farming and food systems. A number of voluntary third-party certifications, such as Fair Trade USA, Rainforest Alliance, and Fair for Life (among others) highlight member farming companies' commitment to safe and healthy working conditions, upholding human rights as defined by the United Nations General Assembly, and providing living wages for employees [89-91].

An environmentally advantageous farming practice characteristic of many locally-focused farms is growing organically [92]. Forty-six percent of first point of sales from organic farming occurs within 100 miles of the farm, and 80% of organic farms in America sell within 100 miles of their operation [93]. While some concerns have been raised about potentially lower crop yields on organic farms [94], such concerns have been debated when taking a broader look at food systems, their impact on communities, and broader-scale effects on the environment [95].

Farmers' markets The number of farmers' markets in the US has nearly quintupled since 1994, growing from 1,755 markets to 8,669 in 2016 [96]. Farmers' markets conceivably contribute to the sustainability of local food systems in multiple ways, most notably by providing a place for small-scale farmers to sell their products and to establish relationships with consumers. Given this, farmers' markets have been considered an alternative market (alternative to conventional retail outlets for customers) [97]. Not only do farmer's markets provide a place for small farmers to sell their products locally, they also contribute to improving diet quality and food security, particularly through use of wireless terminals capable of processing Supplemental Nutrition Assistance Program (SNAP) vouchers [98]. SNAP participants who shop at farmer's markets report higher intake of fruits and vegetables compared to those who do not shop at farmers' markets [99]. Several federally funded programs specifically encourage participation in farmers' markets, such as the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) Farmers' Market Nutrition Program and the Senior Farmers' Market Nutrition Program. Kropf and colleagues have shown that women participating in the WIC Farmers' Market program consumed more vegetables and experienced a higher perceived benefit and diet quality than women participating only in WIC [100]. A recent review demonstrated that participants in the Senior Farmers' Market Nutrition Program consumed more fruits and vegetables than non-recipients of such vouchers [101]. The presence of farmers' markets can contribute toward improving the food security of an area indirectly as well by driving down costs of other retail outlets, such as convenience stores, in food deserts [102].

Community Supported Agriculture (CSA) Whereas farmers' markets have been called an alternative market, CSA has been dubbed an "alternative to the market" [97]. Instead of merely being an alternative place to purchase food, members of a CSA program participate in a shared venture with farmers by paying for a "share" of the produce up front at the start of the season. This helps the farmer providing a guaranteed income at the start of the season to help mitigate the inherent risks involved with farming [103]. CSAs provide many of the same benefits for local food systems and for individual health as farmers' markets. Their organizational structure eliminates the need for a "middle man," potentially returning more profit to farmers [104]. Recent research also suggested that members of CSAs experience increased consumption of fruits and vegetables while part of the program [105]. As such, CSAs have been identified as a potentially useful venue for health behavior change interventions [106]. However, whereas some farmers' markets have reached out to lower income individuals by accepting SNAP and WIC vouchers or by being located in food deserts, CSA membership still largely belongs to those with higher incomes [107]. Nonetheless, in a feasibility study, Quandt and colleagues reported that individuals in a low-income community would be willing to pay $10 per week to participate in a CSA (some participants indicated that they would be willing to pay up to $25 per week to participate in a CSA), and that consumption of fruits and vegetables among participants during a trial period of participating in a CSA increased, albeit not significantly [108].

Food hubs A newer addition to alternative food networks, food hubs typically function as an intermediary connecting smaller, local producers with larger retail outlets.

The currently accepted working definition of a food hub, according to the National Food Hub Collaboration and USDA is, “a business or organization that actively manages the aggregation, distribution, and marketing of source-identified food products primarily from local and regional producers to strengthen their ability to satisfy wholesale, retail, and institutional demand” [109, 110]. Horst and colleagues have described nine types of food hubs, highlighting the multiple functions food hubs serve in communities [111]. Since consumer interest in local foods has been increasing over the last decade [112], food hubs have emerged as a viable means to connect producers with larger retail outlets to help scale up sales for local farmers and to help larger retailers satisfy consumer demand for source-identified products [111]. However, food hubs do not merely serve larger wholesale customers; they can also connect individual consumers with small-scale farmers as part of a values-based supply chain [113]. The term Agriculture of the Middle (AOTM) refers to mid-size producers who may particularly benefit from participating in a values-based supply chain such as a food hub [80, 114]. A survey by Jablonski and colleagues indicates that food hubs could expand their market reach through some logistical changes, and that this would still provide a positive economic impact to the community, even when considering opportunity costs [30].

Local agriculture Although the local foods movement has been growing tremendously and provides many benefits, simply “buying local” may not always be the most environmentally sustainable choice [115]. “Food miles,” or the distance that food travels from production to point of purchase, represent only one factor affecting the environmental impact of food production, and in fact contribute a relatively small percentage of greenhouse gas emissions (GHGEs) associated with food production [116]. In order to assess the environmental impact of the entire process affecting production, transportation, consumption, and waste disposal of a given product (for example, food), an analytical process called Lifecyle Assessment (LCA) has been developed [117]. Pullman and Wikoff have shown that there are slight advantages of purchasing numerous types of products locally as opposed to those from a major distributor, but that larger savings in carbon dioxide emissions resulted from reduced packaging choices and from minimizing food waste [118]. Yang and Elliot also acknowledge the relatively small impact of food miles on the carbon output of food production, but propose other benefits of local food systems if they are designed to recycle energy, water, and nutrients [119].

Each of the venues described above (local farms, farmers' markets, CSAs, food hubs) can contribute toward sustainable local food systems while improving access to healthy foods, and their impact has been studied in a variety of geographic locations both nationally and internationally [25, 27, 28, 31, 34, 35, 79, 80, 120]. However, one region that has been largely unexplored is the southwest of the United States. Given unique environmental challenges such as hot, arid desert conditions, it is possible that farmers on small, local farms in states like Arizona and New Mexico might experience barriers and obstacles unique from those experienced by growers in other regions of the country. Given this gap in the literature, we conducted interviews with 20 farmers in Arizona and New Mexico to ascertain challenges and facilitators of farming in the southwest. This study is detailed further in Chapter 3.

Vegetarian diets and dietary protein

Local farms and programs might have important implications for the diversity, resilience and broad sustainability of food systems. However, they can also contribute to dietary shifts in consumption patterns that impact individual health and environmental sustainability simultaneously. Plant-based diets (including less animal-food intensive, vegetarian, and vegan diets) represent a growing area of interest in the promotion of physical and environmental health for a number of reasons. Observational data shows that vegetarians tend to have better cardiovascular outcomes compared to those consuming omnivorous diets [121, 122]; a reduced risk of developing prostate [123], colorectal [124], and breast cancers [125]; lower body mass index (BMI) [126]; less insulin resistance among postmenopausal women [127]; lower blood pressure [128]; decreased risk of developing metabolic syndrome (MetS) [129, 130]; and lower all-cause mortality [2]. Experimental studies utilizing vegetarian and vegan diets offer similar results. Dietary interventions in which participants adopt a vegetarian diet have induced improvements in lipid profiles of participants including decreases in total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C) independent of weight loss, and triglycerides (TGs) mediated by weight loss [131]. Other research has shown reduced visceral fat, improved oxidative stress markers, and insulin sensitivity among diabetic patients [132]. Although interventions including vegan diets are less common, one experimental study resulted in a reduction in C-reactive protein (CRP), a marker of inflammation, over the course of a three-week vegan dietary intervention [133].

Dietary choices affect the environment as well as human health. Producing plant protein requires less land [3, 6, 7, 11], water [4, 6, 7, 11], and energy [3-7] compared to producing animal protein and results in less GHGEs in aggregate [2, 7, 10, 12, 14]. Meat and other animal products require more life cycle inputs per kilogram of product than plant products [134]. Consequently, following a vegan diet is in many circumstances likely to be the most effective in systemically reducing GHGEs and agricultural land use related to food production and consumption. One other environmental concern that is less well-publicized, but certainly not less important, is the rapidly depleting global supply of phosphorus. Used as a fertilizer for food production, reserves of phosphorus are limited and projected to be depleted within 50-100 years, if consumption trends continue at the same rate [135, 136]. Vegetarian diets require considerably less phosphate to produce than meat-containing diets; as such, shifting broadscale dietary patterns to less meat consumption could be a vital strategy to contend with a looming phosphorus shortage [136].

Not all meat or animal protein exerts the same environmental toll. For example, switching from consuming ruminant meat (such as beef) to monogastric meat (such as poultry or pork) reduces the GHGEs [137]. Avoiding overconsumption of nutrients, including protein (particularly animal protein), has been suggested as a means of reducing environmental impact of diet [138]. Although vegan and vegetarian diets most dramatically reduce GHGEs, following a healthy, yet less-animal intensive diet compared to the average American diet, would also provide environmental benefits [137, 139].

The choice of whether to include animal-derived protein (dairy, eggs, meat, fish, or poultry) in the diet may relate to concerns about physical health, environmental sustainability, ethics related to worker or animal welfare, or religious convictions. Consumer interest in plant-based nutrition is growing, as evidenced by the increase in

Google searches for the term "vegan" over the past five years [140]; 2016 being named the "International Year of Pulses" by the United Nations [141]; and Mintel predicting that 2017 food trends will see a continued emphasis on sustainability and vegetarian, vegan, and other plant-focused formulations [142]. The type of animal protein being consumed is shifting too, according to a report by the USDA ERS, indicating that consumption of red meat is steadily decreasing whereas consumption of poultry is increasing [143].

Several features differentiate plant-based protein from animal-based protein, in addition to source. Proteins are made of amino acids. These include non-essential amino acids that can be synthesized by the body and essential, or indispensable, amino acids that cannot be made by the body and thus must be consumed exogenously through the diet. Functionally, however, all amino acids are essential for normal physiologic functioning [144]. Of the indispensable amino acids, branched-chain amino acids (BCAAs) are particularly important for promoting muscle protein synthesis (MPS) and include leucine, isoleucine, and valine. These amino acids are more concentrated in animal-based protein compared to plant protein [145]. Some proteins, including animal protein, are considered "complete proteins" since they contain all of the essential amino acids in sufficient quantities, whereas many plant proteins are considered "incomplete proteins" since (on their own) they do not contain sufficient quantities of all of the essential amino acids. However, plant proteins may "complement" each other and provide all of the essential amino acids necessary when included together in the diet [146].

Digestion and absorption rates of different proteins can also differ and thus impact postprandial MPS rates. As such, some proteins (such as whey) are considered a "fast" protein since they are rapidly digested so that their amino acids appear quickly in the bloodstream, whereas other proteins, such as casein, are considered “slow” proteins since they result in a slower, yet more prolonged, rise in aminoacidemia [147]. Soy protein is also considered a fast protein, although it does not stimulate MPS to the same extent as whey protein even when both protein sources provided 10 grams of EAAs, an amount considered sufficient to induce maximal MPS in young adults (about age 30) [61]. This may be due to differences in amino acid composition (specifically, a lower leucine content) [148]. Another difference between animal or plant proteins is the presence or absence of antinutritional factors, compounds that affect digestibility of the protein. Antinutritional factors may be naturally occurring, such as glucosinolates, trypsin inhibitors, hemagglutinins, tannins, phytates, and gossypol. They may also be formed by heat or alkaline processing of protein foods [149]. These factors work in different ways to reduce the digestibility of protein, and they are found in plant foods such as beans, legumes, soybeans, and cereals. However, in spite of differences between plant and animal protein, consuming a balanced vegetarian or vegan diet that includes a variety of plant protein sources has been shown to be nutritionally adequate in terms of providing sufficient amounts of essential amino acids [146, 150] and has consistently been supported by groups such as the Academy of Nutrition and Dietetics [146, 151, 152].

As a reflection of amino acid composition, digestibility, and overall quality, various scoring systems for protein-containing foods have been created. One of the most widely used methods was developed in 1989 when the Food and Agriculture Organization and the World Health Organization convened an expert consultation to quantify the quality of proteins through the Protein Digestibility Corrected Amino Acid Score (PDCAAS) [153]. To calculate the PDCAAS of an individual food, one must determine the macronutrient composition of the food, the amino acid profile of the protein in the food, the amino acid score, and protein digestibility. To determine the amino acid score, it is necessary to calculate the milligrams of each amino acid in the test protein and divide it by milligrams of the same amino acid in a reference protein. The amino acid with the lowest ratio is the limiting amino acid, and its amino acid score would be attributed to the protein as a whole for its overall amino acid score. The PDCAAS is predicated upon true fecal protein digestibility, which is determined by the "rat balance method" [153]. In this method, body weight of a rat is measured at baseline and the end of an observation period, and the amount of nitrogen in the rat's consumed food, leftover feed, urine, and feces are measured over a given period to determine oxidation rate of the protein. A drawback of this method is the difficulty differentiating intestinal nitrogenous secretions from fecal nitrogen resulting from food ingestion [154]. The requirement pattern for each amino acid has been determined through human studies with preschool-aged children through the Institute of Nutrition of Central America and Panama (INCAP). The Working Group on Protein Quality Measurement further determined that indispensable amino acid needs for preschool-aged children is the most suitable for all ages, except infants [153, 155].

While the PDCAAS has been helpful for comparing protein quality between foods, it has limitations. First, PDCAAS scores are truncated at 1.00, even though some proteins could have higher values than 1.00 if this were permitted by the method [153, 155]. Secondly, PCDAAS values likely overestimate protein quality since the method relies upon fecal (not illeal) analysis of protein digestibility. This is problematic since some of the nitrogen disappearance in the large intestine is due not to protein digestion and absorption, but rather to microbial degradation, resulting in ammonia production, absorption, and excretion as urine [156]. Given these concerns, an updated assessment of protein quality was created in 2011 by the Food and Agriculture Organization Expert Consultation called the Digestible Indispensable Amino Acid Score (DIAAS) [155]. The primary differences between DIAAS and PDCAAS are that the DIAAS is calculated using illeal digestibility and values are not truncated.

In spite of these protein quality assessments, current recommendations about amount of protein to consume do not directly address the quality of protein. The Acceptable Macronutrient Distribution Range (AMDR) states that protein should provide 10-35% of daily calories in the diet, and the Recommended Dietary Allowance (RDA) for protein is 0.80 grams of "good quality protein" per kilogram of body weight per day (g/kg/day) [157]. This is based on the minimum amount of protein needed to achieve body nitrogen equilibrium (zero balance) in healthy adults as determined by nitrogen balance studies [158]. However, it has been contended that using improved methodologies, such as indicator amino acid oxidation, suggest higher protein intakes (1.2-1.6 g/kg/day) to optimize health, not simply meet minimal needs for the general population [159]. Indicator amino acid oxidation determination of protein needs is based on the concept that when one indispensable amino acid is insufficient for synthesizing protein, all indispensable amino acids will be oxidized. As more of the rate-limiting indispensable amino acid is consumed, oxidation of other indispensable amino acids will decrease. The requirement of the limiting indispensable amino acid is met when oxidation of this indicator amino acid ceases to change [160]. The concept of optimizing health versus meeting minimal needs for various nutrients is a bit nuanced as the definition of "optimal health” may vary depending upon one’s goals (for example, preventing chronic disease compared to building muscle mass to help prevent sarcopenia and maintain independence later in life).

Accurately estimating protein needs is vital as protein acts as both substrate and stimulus for MPS, even independent of an exercise stimulus [161]. Previous work has demonstrated that muscle protein anabolism resulting from amino acid ingestion is primarily attributable to consumption of indispensable amino acids [162]. Specifically, BCAAs increase the rate of MPS and decrease the rate of muscle protein breakdown by influencing multiple signaling pathways [163]. Of these BCAAs, leucine is a particularly important regulator of MPS through its stimulation of several signal transduction pathways that control mRNA translation, leading to an upregulation of skeletal muscle protein synthesis [55, 164]. These pathways converge at the mechanistic target of rapamycin complex 1 (mTORC1) which, once activated, phosphorylates ribosomal protein S6 kinase 1 (S6K1) and 4E binding protein 1 (4E-BP1). These proteins then help initiate translation [57]. The importance of mTORC1 as a means for leucine to stimulate MPS has been highlighted through administration of rapamycin, an inhibitor of mTORC1. In the presence of rapamycin, leucine does not stimulate translation initiation [56]. Leucine works synergistically with and independently of insulin to stimulate MPS and to inhibit muscle protein degradation [58]. The concentration of leucine typically seen in high-quality proteins appears to be sufficient to elicit maximal muscle protein synthesis among healthy young people, as consuming a solution of EAA with a higher concentration of leucine (3.5 vs 1.8 grams in a 10 g EAA solution) did not induce greater muscle protein synthesis; however, muscle protein breakdown was reduced only in the higher leucine group [61]. As net muscle protein balance results from the difference between breakdown and synthesis, it is possible that the higher concentration of leucine might have beneficial longer-term effects for anabolism.

Variables that affect dietary protein requirements to optimize MPS include age, physical activity expenditure, and energy balance. Young adults need less protein per meal or snack (0.24 g/kg) to maximally stimulate MPS compared to older adults (0.40 g/kg) [165]. Physical activity level also affects protein needs. Although the Dietary Reference Intakes do not make specific provisions for athletes, the American College of Sports Medicine, the Academy of Nutrition and Dietetics, and Dietitians of Canada in a joint position statement recommend athletes consume 1.2-1.7 g/kg/day [150]. During times of energy restriction, in order to promote retention of lean body mass, athletes may be encouraged to consume up to 2.0 g/kg/day [166].

Timing and distribution of protein consumption throughout the day are also important factors impacting MPS. It is not enough to fixate upon consuming a total amount of protein per day without considering distribution and timing of the protein intake. Consuming protein evenly throughout the day instead of in skewed distributions results in greater MPS [167], which is advantageous for building and preserving lean body mass. Additionally, exercising prior to consuming protein enhances anabolic responsiveness to dietary protein consumption [168, 169]. Distributing protein consumption throughout the day may include a pre-sleep protein feeding. Recent work has shown that this promotes MPS overnight, a time when people are typically not in an anabolic state, and the response is augmented when preceded by resistance training [170].

Another variable influencing plasma amino acid concentrations in response to protein consumption is the form of the protein consumed. Liquid protein ingestion compared to a solid form induces higher plasma amino acid concentrations when the beverage and solid food are isoenergetic and matched for macronutrient composition [171]. A different study showed that area-under-the-curve for plasma amino acids was the same after consuming either liquid or solid protein; however, plasma aminoacidemia rose to its peak concentration twice as quickly with the liquid form of protein compared to solid [172]. These differences in rates of MPS may affect long-term anabolic potential.

Vegetarian diets and exercise performance

In spite of the marked differences in food consumption of vegetarians, vegans, and omnivores, literature about the effect of dietary pattern on athletic or sport performance outcomes is sparse. Although often criticized as being less rigorous than randomized controlled trials (RCTs) since they cannot lead to conclusions about causation, observational studies may be advantageous in some ways when comparing vegetarian and omnivorous athletes. Many exercise or sport-related RCTs simply assign omnivores to a vegetarian diet for a brief period of time and extrapolate conclusions to athletes who follow vegetarian diets long-term. It is possible such an approach is overly simplistic and within the context of brief interventions cannot provide strong conclusions related to dietary patterns and their overall effects on an athlete's performance. It is therefore useful to consider first the broad-scale differences in dietary and nutrient intake among vegans, vegetarians, and omnivores, then examine the current state of the literature pertaining to effect of vegetarian or vegan diet patterns on exercise and fitness-related outcomes including cardiorespiratory fitness, strength, and power.

Important differences exist in terms of nutrient intake depending on the level of animal-food restriction. A large cross-sectional study (n=1475) of omnivores (n=155), pesco-vegetarians (n=145), semi-vegetarians (defined in this study as those who consume meat, fish, or poultry no more than once per week) (n=498), vegetarian (n=573), and vegans (n=104) compared macro- and micronutrient intakes by dietary pattern [42]. Data indicated that omnivores consumed more total energy, saturated fat, cholesterol, sodium, and protein but less fiber, calcium, and iron than vegetarians [42]. Vegans consumed the least energy, saturated fat, sodium, and calcium, but the most fiber and iron. Other studies with smaller sample sizes have largely substantiated these observations [43, 44, 173]. These studies were not specifically among athletes, however, and determining whether such nutrient intake differences exist among trained athletes remains a gap in the literature. Given the essential role of carbohydrate for energy production during exercise, particularly at high intensities, and of protein for building and repairing muscle tissue, differences in patterns of consumption between vegetarians and omnivores could theoretically lead to differences in exercise performance and recovery capacity. To help fill this gap in the literature, we conducted a cross-sectional study of 70 endurance-trained athletes, which included having participants complete a 7-day food log. For the complete study, please see chapter four.

Endurance exercise

Athletes training for endurance sports versus strength and power-oriented sports have different training and fueling needs. As such, following a vegetarian diet may have different effects on performance outcomes for these athletes. Many studies assess the diet's potential for impact on performance outcomes indirectly by measuring maximal oxygen uptake, strength, blood acid-base status, acute MPS, and chronic muscle growth instead of actual performance in sporting events.

A study by Hanne and colleagues compared vegetarian and omnivore athletes (primarily endurance athletes) matched by type of sport on a number of parameters. Maximal oxygen uptake (VO2 max) was indirectly predicted by a stress test on a cycle ergometer, and a Wingate anaerobic test provided measurements of total power, peak power, and percent of fatigue. Neither aerobic nor anaerobic capacity significantly differed between vegetarians and omnivores [63]. While this study is one of the few to compare vegetarians who had adhered to their dietary pattern for at least two years, a drawback was that maximal oxygen uptake was only indirectly estimated, although true maximal tests are not usually contraindicated with athletes. Additionally, there was no analysis of nutrient composition of the diet.

In a cross-over design, Hietavala and colleagues examined the impact of adopting a vegetarian diet for four days prior to completing a graded exercise test on a cycle ergometer. Participants on the vegetarian diet had higher oxygen consumption at a given workload, although this did not reduce their maximal aerobic performance. However, not only was source of the dietary protein changed for participants in this study, they also had their habitual daily protein intake of 1.59 g/kg reduced by nearly half to 0.8 g/kg. Thus, it was not possible to determine whether dietary protein amount, source, or other dietary change (such as the concurrent reduction in total calories and dietary fat) may have influenced these performance results [174].

Another cross-over design examined the impact of following a vegetarian diet for six weeks on a number of physiologic and performance outcomes among trained male endurance athletes (mean VO2max 67 ml/kg/min). Mixed diets included 58% of calories from carbohydrates, 27% by fat, and 15% by protein. Vegetarians diets similarly had 58% of energy from carbohydrates, 28% from fat, and 14% from protein. Additionally, the amino acid composition of the diet was not significantly different between groups. To assess exercise endurance, participants began a test on either a cycle ergometer or treadmill at a workload corresponding to 100-120 heart rate beats per minute (bpm). Every 15 minutes the workload was increased corresponding to an additional 10-15 bpm. This was continued until exhaustion, and time to exhaustion was used as an indicator of exercise endurance capacity. Maximal voluntary contraction and isometric endurance at 35% of maximal voluntary contraction for elbow flexors and the quadriceps were determined by a strain-gauge when the participant was sitting upright. There were no significant differences between groups for VO2 max, time to exhaustion on the endurance test, maximal voluntary contraction, or isometric endurance upon adoption of the vegetarian diet [46].

Recent case studies have also highlighted the capabilities of prominent vegan endurance athletes [175, 176]. While such case reports are hardly sufficient for making recommendations about adequacy of a vegetarian or vegan diet for endurance athletes, a large study (target n=1500) is in progress comparing running performance among omnivore, vegetarian, and vegan runners, and results are forthcoming [177]. This study may serve as a model for other studies that could investigate impact of dietary pattern on other types of sport, such as triathlon or cycling.

Anaerobic (strength and power) exercise

The role of adoption of a vegetarian diet on strength and power performance has been investigated as well. Some of this research has involved examining differences between vegetarians' and omnivores' physiological concentrations of creatine and carnosine, and how these differences may influence anaerobic activities. Beta-alanine is the rate-limiting precursor to forming carnosine, the main buffer in human skeletal muscle tissue, and beta-alanine is found in meat, fish, and poultry. As there is a positive correlation between buffering capacity and high-intensity exercise performance, it is important to determine whether adoption of a vegetarian diet could impact muscle buffering capacity and consequently sprint or high-intensity performance. Baguet and colleagues conducted a five-week intervention in which participants were randomized to either a lacto-ovo vegetarian group (supplemented with one gram of creatine in order to compensate for a lower creatine content in the diet compared to the other group) or an omnivorous diet, and all participants engaged in sprint training 2-3 times per week. Power output increased during sprints on a cycle ergometer for both groups, with no significant between-group differences, and muscle carnosine concentrations did not change significantly from baseline in either group. There was a significant time-by-group interaction for carnosine concentration in the soleus with a non-significant decrease in the vegetarian group and a non-significant increase in the omnivorous group, but this did not affect buffering capacity [47].

Creatine levels represent another important physiological difference between vegetarians and omnivores that could affect performance. Vegetarians generally present with lower total creatine levels. However, this difference appears to make them more receptive to creatine supplementation and its effects, as vegetarian participants receiving a creatine supplement exhibited greater increases in total creatine, phosphocreatine, lean body mass, and total work performed doing leg extensions and flexions on an isokinetic dynamometer compared to omnivores receiving creatine supplementation and undergoing the same training program [178]. There were no significant differences in total work output at baseline between groups, in spite of the lower total creatine levels.

Shomrat and colleagues also conducted a creatine supplementation study among vegetarians and omnivores, and compared peak and mean power output during modified Wingate tests, plasma creatine, and changes in lean body mass. At baseline, the only difference between vegetarians and omnivores was plasma creatine levels, a difference that did not significantly impact mean or peak power output during the modified Wingate tests. Post-supplementation, both groups had similar increases in mean power output, but only omnivores increased their peak power output [179].

In addition to plasma creatine and carnosine, muscular strength and lean body mass are important contributors to success in many sports, and help to preserve quality of life and independence with aging. Therefore, several training studies have been undertaken to compare the effect of a lacto-ovo vegetarian and omnivore diet, or supplementation with a plant versus animal-derived protein supplement, on strength and lean body mass changes in conjunction with a resistance training program.

Campbell and colleagues conducted a 12-week long resistance training program with male participants ages 51-69 who were randomly assigned either to continue their habitual omnivorous diet or to adopt a self-selected lacto-ovo vegetarian diet [180]. At the end of the 12 weeks of training, the men assigned to the LOV group did not increase lean body mass as much as the group maintaining their mixed diet, although both groups increased strength comparably. However, mean protein intake decreased from 1.09 g/kg of protein per day at baseline to 0.78 g/kg among the LOV group at week 11, a value that is below the RDA. Conversely, those maintaining their mixed diet increased their protein intake from 0.91 to 1.0 g/kg/day. While these changes in protein intake did not reach statistical significance, it is plausible that they may have contributed to differential lean body mass development [180].

Another study with older men (mean age 65± 5) compared body composition and strength changes between groups assigned to an LOV or a beef-containing diet. Both groups consumed an LOV diet for two weeks prior to the 12-week resistance training program. Then they received 0.6 g/kg/day of protein from either beef or soy protein. The rest of the protein in their diets came from self-selected sources. Mean total protein intake (g/kg/day) at weeks 1, 3, and 15 for LOVs was 1.06±0.2, 1.17±0.1, and 1.15±0.1; for beef-consuming participants, it was 1.00±0.2, 1.10±0.2, and 1.03±0.3. There were no significant group differences in terms of strength improvement, increase in the size of muscle cross-sectional area, or body composition change. Additionally, resting energy expenditure and concentrations of muscle creatine, phosphocreatine, and total creatine did not change over time or differ between groups significantly [181].

A 2012 meta-analysis of 22 randomized, controlled trials showed that irrespective of source, dietary protein supplementation compared to either placebo or carbohydrate supplementation, in conjunction with strength training, could elicit superior developments in fat-free mass and strength in both younger and older participants [182]. While few studies currently exist comparing anabolic and strength development responses to a training program between vegetarian and omnivore participants, more work has been done assessing impact of supplementing with either a plant or animal based protein in training studies, or MPS protein synthesis, breakdown, and balance. However, chronic training studies comparing soy and whey protein supplementation have yielded mixed results. This may be due to methodological differences between studies, and it highlights challenges of working in “real-world” situations with free-living human participants. Lack of consistency in results may be due to the varying amounts of protein provided as a supplement, different baseline dietary intakes of protein, length of the intervention, or lack of objective means for assessing compliance to dietary protocol.

Results from a nine-week long study involving consuming either soy or whey protein bars (each containing 11 grams of protein) three times per day in conjunction with a strength training routine showed no significant differences between protein groups for increasing lean body mass. While both protein-supplemented groups significantly increased their lean body mass from baseline, the training-only group did not [183].

Candow and colleagues also found no significant differences between groups supplementing with either 1.2 grams of protein per kilogram of body mass (g/kg) of whey protein or soy protein in conjunction with resistance training for six weeks on lean body mass or strength changes, although both groups increased lean body mass more than a group supplementing with an isocaloric carbohydrate supplement. Similarly, although all groups increased one-repetition maximum (1-RM) weight for squats, both protein groups improved their 1-RMs more than the carbohydrate group, with no significant differences between protein groups [51]. This lack of difference in group response could be due to the very large amounts of protein consumed. The protein supplement alone provided 1.5 times the Recommended Dietary Allowance for daily protein intake, and participants consumed protein in their regular diet as well.

Another study that involved supplementing protein in large amounts (two doses of 25 grams of protein daily) found no differences in lean body mass between groups receiving either soy concentrate, soy isolate, a soy isolate and whey blend, or whey blend only. Although participants engaged in strength training for 12-weeks, changes in strength were not reported [52]. Phillips has noted that most high quality protein sources (such as whey and soy) are made of ~40% EAAs, so that a serving of 25 grams of high quality protein has ~10 g EAA- an amount shown to be sufficient to maximally stimulate MPS [184].

A third study involving supplementing with a large amount of protein (48 grams) from either rice protein or whey protein led to similar increases in lean body mass, strength, and muscle thickness and similar decreases in body fat between groups [50]. In addition to the large protein supplement, participants' diets were controlled to have 25% of their calories coming from protein, an amount higher than the typical American average of 13.5-16.0%. Even the 95th percentile of protein intake was only 20.8% in the demographic recorded to consume the most protein [185].

However, following a 12-week resistance training program in which participants trained five days per week on a split-body routine, Hartman and colleagues found that consuming skim milk (which contains whey) post-exercise contributed to greater type II muscle fiber area and fat-free and bone-free mass increases compared to the group consuming an isocaloric, macronutrient profile-matched soy protein supplement or isocaloric maltodextrin placebo. Both skim milk and the soy beverage contained ~17.5 grams of protein. In spite of the differences in fat- and bone-free mass development, there were no significant group differences for strength increases [53].

Perhaps one of the most sophisticated and lengthy resistance-training intervention studies to date, conducted by Volek and colleagues, involved a nine-month long training intervention and supplementation with either whey protein (21.6 g), soy protein (20 g), or an isocaloric carbohydrate placebo. While all groups increased their lean body mass, the group supplementing with whey protein significantly increased their LBM more than either soy or carbohydrate. However, this difference in lean body mass accrual did not translate into greater strength gains for the whey group compared to the soy or carbohydrate groups [54].

Instead of comparing whey and soy protein isolates, Reidy and colleagues compared whey protein isolate (~18 g) and a soy-dairy blend (~19 g made of 25% soy protein, 25% whey protein, 50% casein) with an isocaloric maltodextrin placebo in conjunction with a 12-week strength training program. All groups similarly increased muscle strength and thickness, and there was no significant group effect on lean body mass changes.

However, there was a trend ($p=.093$) for the protein-blend group to have a greater lean body mass change from baseline to post-intervention compared to the other groups [186].

Complementing training studies, stable isotopic methods and muscle biopsies have been used to quantify acute MPS, breakdown, and net turnover in response to ingestion of different types of protein. Reidy and colleagues compared mixed-MPS and mTORC1 signaling in response to ingestion of either whey protein or a blend of soy and dairy proteins following a bout of high-intensity resistance exercise in a group of healthy young males and females. Although whey protein resulted in an earlier and more elevated rise in branched chain amino acids (BCAAs) in the blood, the protein blend maintained elevated levels of these amino acids in the blood longer. The fractional synthetic rate (FSR) following exercise was comparable between groups immediately post-exercise but remained elevated only in the protein blend group four hours post-ingestion. mTORC1 signaling was similar between groups at all time points, except at five hours post-exercise in the whey protein group, where phosphorylation of S6K1 did not increase [60]. The protein blend was made of 50% protein from sodium caseinate, 25% whey protein isolate, and 25% soy protein isolate. Interestingly, protein sources were matched for leucine content instead of total protein content, with the dose based upon previous work showing that 8.6 grams of essential amino acids in intact protein maximally stimulates the fractional synthetic rate after resistance exercise in healthy young men [187]. However, given the rather small contribution of soy protein to the blend, the actual amounts of total protein were not very different between groups (19.3 ± 1.1 g versus 17.7 ± 0.9 g protein for protein blend and whey protein isolate groups, respectively).

Similarly, Borack and colleagues demonstrated post-exercise blood amino acid concentrations, mTORC1 signaling, and MPS, breakdown, and consequently balance was similar between groups of older men (55-75 years) consuming either whey protein isolate or an isonitrogenous (30 g protein) soy-dairy blend. In this study also, only 25% of the protein in the soy-dairy blend came from soy protein. Fifty percent of the protein was from sodium caseinate and 25% was from whey protein isolate [188].

A study by Yang and colleagues compared whole-body leucine oxidation and MPS in response to either 20 or 40 grams of soy protein isolate and a bout of unilateral leg extension resistance training. These values were compared with those previously documented values for consuming either 20 or 40 grams of whey protein isolate in elderly men. The whey group exhibited greater rates of MPS for both 20 and 40 grams compared to their soy counterpart. Furthermore, 20 grams of soy protein did not significantly differ from a group that did not ingest any protein [189].

One key gap in the literature is that all but one of the training studies including protein supplementation have matched protein sources nitrogenously instead of by leucine content. The one study that matched for leucine compared a soy-dairy blend instead of a 100% plant protein with whey. Consequently, when comparing soy and whey supplements (or any other plant and animal protein), supplements used in studies contain differential amounts of leucine, other BCAAs, and other EAAs. Given the key role of leucine for MPS and inhibiting muscle protein breakdown, it is important to examine whether matching protein sources for leucine content instead of total nitrogen would alter gains in lean body mass and/or strength in response to a strength training program in conjunction with protein supplementation. To help address this gap in the literature, we conducted a study comparing the effect of supplementing with either soy protein isolate or whey protein isolate, each containing two grams of leucine, in conjunction with a 12-week supervised training program among healthy, untrained males and females ages 18-35. For the complete study, please see chapter five.

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CHAPTER 3

SMALL FARM SUSTAINABILITY IN THE SOUTHWEST: CHALLENGES, OPPORTUNITIES, AND BEST PRACTICES FOR LOCAL FARMING IN ARIZONA AND NEW MEXICO

Introduction and literature review

Consumer interest in and demand for local produce has increased considerably in recent years. As a result, local food venues that provide opportunities for direct-to-consumer marketing, such as community supported agriculture programs (CSAs) and farmers' markets, have grown steadily in number [21]. Strong consumer interest in more locally produced foods represents an important opportunity for greater support of smaller-scale farm operations whose market focus is often local or regional in nature.

Even so, many small-scale, locally focused farmers struggle to maintain viability due to numerous challenges. Barriers to financial viability in small-scale farming have been well-documented in various regions of the country [27, 35, 79, 80]. Across studies and regardless of geography, particular challenges consistently emerge as issues for farmers. These include difficulties in marketing and consistent labor as well as struggles with cost and compliance with potentially valuable certifications.

Effective marketing strategies and a lack of access to markets have consistently been reported by local farmers across the US as key difficulties. Farmers note that market access and marketing impact both near-term maintenance of operations as well as opportunities for future growth [27, 28, 31]. Factors contributing to these challenges include competition with larger national and international growers [190] and the inherently capricious nature of sales in direct-to-consumer venues [34]. Farmers' markets in particular require a high input of labor and time, and do not necessarily lead to reliable sales [31]. At the same time, lack of regulations pertaining to labeling and claims made about food sold at farmers' markets is a concern for many small farmers. Without a regulatory agency verifying claims, there is a perception that anyone can sell produce directly to consumers without proof of origin, regardless of whether that food was actually grown at a nearby farm [27, 28].

In an effort to improve viability, many small farmers thus rely on a combination of direct and wholesale marketing [29]. However, in order to sell wholesale, especially in larger markets or to larger institutions, farmers are often asked to produce a higher volume of product of uniform quality and aesthetics [27]. Simultaneously, many opportunities for wholesale marketing require certifications, such as 'certified organic' or GHP/GAP (good handling practices/good agricultural practices), which many small farmers feel are designed to favor large farms given the potential cost and regulatory requirements involved [80, 87].

Labor represents another important barrier for smaller-scale farms due to its expense [79]. Large-scale farms can better manage the cost and management involved; whereas international farms generally pay lower prices for labor, domestic large-scale farms can offer year-round employment for laborers in order to retain a reliable workforce [120]. Small-scale farms, on the other hand, usually retain labor only during growing seasons and often must raise prices on their products to better manage the higher cost of potentially inconsistent labor [27, 28].

These and other concerns have been well studied in many parts of the US, but less so in the southwest. Many of the same issues – as well as potentially novel factors given the unique geography – are likely to threaten the viability of small-scale farms in this region. In Arizona and New Mexico, for example, farms number more than 20,000 per state, and most are small-scale operations [191]. Eighty percent of farms in Arizona are less than 50 acres in size, and 63% of Arizona farms generate less than $2,500 in revenue annually [191]. In New Mexico, 51% of farms are less than 50 acres in size, and 55% of New Mexico farms generate less than $2,500 in revenue annually [192]. Consequently, most farmers must work a second job or simply view farming as a supplementary activity. Adding to concerns about the viability of farm operations in this region, farmers in Arizona and New Mexico are on average 61 and 60 years of age, respectively, above the national average of 58.3 years [191]. Without a competitive marketplace into which a new generation of young farmers can enter, it remains unclear how and if farming at the small-scale in the southwestern region of the US can survive into the future.

To our knowledge, barriers and opportunities related to small-scale farming in the southwest have yet to be researched to the extent they have been investigated elsewhere in the country. As such, the focus of this qualitative study was to explore the struggles, opportunities for success, and other issues to related to the sustainability of small-scale farming in Arizona and New Mexico.

Materials and methods

Developing the survey questionnaire

A semi-structured questionnaire was developed based upon the 2013 National Food Hubs Survey for interviews with farmers in Arizona and New Mexico [110]. The survey was adapted to include a set of demographic items relating both to operators of farms as well as the size and scope of farm operations themselves. Open-ended questions included those focused on challenges, barriers, and motivations for farming. The research team reviewed several drafts of the adapted semi-structured questionnaire until there was consensus about the wording of each question.

Farmer interviews

This study was approved by the Institutional Review Boards at Arizona State University and at New Mexico State University. In New Mexico, nine (n=9) grower interviews were conducted on-farm between May and August, 2015. Contacts of the principal investigators were originally selected for interviews, and other farmers were contacted through snowball sampling. To maintain the focus on small-scale farming, recruitment of farmers also occurred at farmers' market in southern New Mexico. Interviews were recorded using a TASCAM DR-07MKII Portable Digital Recorder, then transcribed by hand. Transcriptions were entered into Microsoft Word and uploaded into QSR International NVivo 10 software to be coded and analyzed.

In Arizona, eleven (n=11) farmers were recruited to be interviewed through snowball sampling. An initial list of three farmers was proposed by the principal investigators through personal contacts, and other names were suggested by these farmers. A food hub employee familiar with many farmers in Arizona also provided potential interviewees' contact information. Telephone and in-person interviews in Arizona were conducted between March and June 2015, recorded using a TASCAM DR-07MKII Portable Digital Recorder, then transcribed using an online software (https://transcribe.wreally.com). Transcriptions were converted into Microsoft Word format and uploaded into QSR International NVivo 10 software to be coded and analyzed.

Eighty percent (16/20) of farms included in the analysis in both states have fewer than 50 acres of land and all are owned by individuals. Although data were not collected about the farms' gross sales annually, our selection of farms most closely resembled that of "small family farms" by the USDA Economic Research Service criteria [83] (Table 1).

Table 1. Characteristics of farm operations and farmers participating in interviews

Demographics of farmers interviewed	Arizona (N=11)	New Mexico (N=9)
Gender (%M/F)	55/45	55/45
Age (years)	<30: 0%	<30: 12%
	30-50: 45%	30-50: 25%
	>50: 55%	>50: 63%
Originally from southwest	36%	53%
Size of operation (acres)	<20: 2	<20: 6
	20-50: 6	20-50: 1

	>50: 1	>50: 1
Farming is primary source of income	50%	44.4%

Coding interviews

A descriptive codebook was developed based upon initial themes that emerged from interviews. The codebook was arranged by overarching themes and their associated subthemes. Each subtheme had its own description and example quote from an interview. Themes and subthemes from interviews were coded in NVivo, and the number of occurrences of each theme and subtheme were recorded. Three rounds of inter-rater reliability using multiple interview samples were conducted to ensure that investigators coding the interviews perceived and coded themes consistently. In this process, investigators coded interview samples separately and then compared coding. In places where there was initial lack of accord in coding, themes were discussed and agreed upon. The codebook was initially developed by investigators in Arizona, and it was expanded upon by researchers in New Mexico. Once consistency was established across all coders, the codebook was finalized and used as a guide to complete coding of all transcripts.

Results and discussion

Although a number of studies have addressed various aspects of local farming in other areas of the country [28, 35, 79, 80, 193], to the authors' knowledge, this is the first to explore these themes in the southwest region of the United States. The farmers interviewed in this study reported many of the same challenges as those expressed in studies of other farmers across the country, as well as some that appeared unique to this region.

Several key themes emerged from interviews with farmers in both Arizona and New Mexico, particularly the numerous challenges, needs, perceived solutions and opportunities, best practices, and motivations related to farming in this region. Some of the main challenges noted reflected those identified in other studies as well as some novel concerns, including labor issues, the high costs associated with farming, and risks related to weather, land, and water. Needs named by the farmers included the importance of developing efficient operations and market opportunities, developing good relationships with customers, and gaining access to reliable water. Perceived solutions and opportunities included providing for greater access to grants and programs that support small-scale farmers and local market outlets. Farmers tended to share some common motivators such as wanting to contribute to a sustainable food system, community development, and enjoyment of farming. Best practices that were offered as a form of advice for new farmers included gaining experience on a farm and being aware of the nature of the job prior to starting a unique operation.

Challenges

Of all the themes discussed by farmers, “challenges” predominated. The subthemes of “capital and costs” and “labor,” which were closely related, were the most commonly cited challenges, followed by risks related to water and land availability. Nine farmers named costs or capital as a key challenge, and the theme of labor emerged in interviews with ten farmers.

With respect to capital and costs, a grower in New Mexico described how difficult it can be to manage the multiple expenses incurred running a small-scale operation:

> There are bills to pay. . .Water, taxes, fertilizer, fuel, maintenance, repair, labor cost. It still…it is quite an endeavor.

Another grower reflected these concerns related to cumulative costs of equipment and implements:

> [One piece of equipment] costs like two-thousand…everything is so cost prohibitive that you really got to commit. But I mean, I've got a tractor that goes eight miles an hour and it cost more than a Ferrari…

Other costs associated with farming, such as growing organically, were considered substantial as well. Due to the high costs associated with farming, many farmers rely on another source of income to supplement their income. In fact, of the farmers interviewed, 56% of farmers in New Mexico and 50% of farmers in Arizona did not consider farming their primary source of income.

A grower in New Mexico described the need to have supplementary income given the expense related to small-scale farming:

> [You need] to have some sort…of income, while you're trailing that whole farming industry, especially if you are trying to keep it on an organic route.

A farmer in Arizona echoed the concern of making a livable salary given the high costs associated with farming. In describing what she thought new farmers should consider in relation to running a new farm operation, the farmer said:

> Oooh. Well, the right answer is go get a real job. However, probably what you want to hear is something that would help make them successful in farming.

And a New Mexico farmer noted:

> Just having a proper balance between just making sure I can earn a living, you know this is my source of income, this is how I pay my bills. This is how I put other food on my table and gas in my truck. You got to realize that you're not volunteering your time.

The high costs associated with farming are also often what prevent farmers from expanding their operations, even if expansion could lead to increased revenue. While most farmers reported wanting to sell more in the future, one farmer remarked in relation to what holds farmers back from increasing production:

> It's just the money to invest in the equipment that you need in order to get set up in a cost effective way to do it.

One common way of providing evidence of certain standards of food production is through third party certifications. These certifications are often perceived to be costly and possibly prohibitively so for some small-scale farmers. Yet in order to increase sales to other markets, often times such a third-party verification (for example, certified organic) is expected or required. One farmer observed,

> You have to be a big enough grower to be able to justify bringing in a third-party certification, assuming that you pass and you understand the process and you don't have any hiccups and they don't require anything very expensive.

Another farmer shared frustration about how she feels that her farm's production follows proper food safety guidelines, yet the farm cannot afford a certification that reflects this.

> Cold storage, building structures, all that is important, and so in order to increase capacity and grow more food and scale- it's scaling up, all of this is extremely important so not only are we scaling up production, but also we need to look at if we scale up production, how are we going to house it? Ok, how are we going to cool it? How are we going to package it? Where are we going to do that? What, you know, becomes the safe model that allows us to funnel product into schools, ok? Because there's guidelines, laws, rules, regulations, and I'm not saying that those guidelines, rules, and regulations always are valuable to the farmer, ok, they sometimes undermine the actual ability to grow food and distribute it…And I

> don't think I'm any less clean than a stainless steel kitchen because we pay attention to it.

Even in a region with good weather almost year-round, growers in the southwest still face the challenge of farming as an inconsistent source of income and thus seek to maximize efficiency of operations. A farmer in New Mexico shared,

> You have to make it worth your while, or else why even do it, you know? …just trying to balance that make sure I have a steady stream of income year-round.

The theme of labor as a challenge was also prominent across interviews. Some growers commented that it is a best practice to offer fair pay for their employees.

> Labor is our highest expense barnone because we want to pay our people as fairly as possible; we want to provide year-round employment for our people.

Another Arizona farmer noted that labor is about more than just pay, but also about a safe working environment.

> It's all about paying them what they're worth, paying them fairly; it's about providing a safe work place for them.

The cost of worker's compensation is particularly high in Arizona, according to one grower.

> We've had lots of employees in the past, but labor being our biggest expense and most challenging thing to manage, we try to stay away from it as much as possible. And workman's comp is really tough in this state [Arizona], so we paid roughly 40 cents…for every dollar we paid employees in the past couple of years, and so that's another incentive not to have employees.

While the above challenges have been noted consistently in other areas of the country, weather, water, and land arose as challenges in occasionally unique ways for farmers in New Mexico and Arizona. The hot, arid climates of these states, combined with unpredictable weather patterns (particularly rain) pose challenges for farmers that may differ from other parts of the US. One farmer described the problem of weather in Arizona in relation to stretches of heat and lack of rain:

> You can't control weather and…there's a lot of uncertainty in weather, and so we have some year to year changes, it changes from week to week, and that brings its own set of challenges.

Not only is the weather challenging for growing conditions and harvesting, it also poses issues related to sales, for example, at farmers' markets that are subject to extreme heat and weather events.

> Everything has to go exactly right, if it starts pouring or raining you have $5,000 worth of produce in your truck. You know, if the truck breaks down and doesn't make it to market, you still have $5,000 worth of produce in your truck.

"Land" was also reported as a challenge by farmers in both states, but the reasons why were not always similar to those noted in other states. Biotic issues, such as pests and pest control, water availability, and poor water and soil quality, were described as challenges in Arizona and New Mexico. A grower in New Mexico surmised that "the obstacles general involve nature." An Arizona grower stated that,

> I guess the most challenging is dealing with the natural elements, such as gophers and squirrels, and everything else that wants to eat their share of the crops.

But in other studies, chemical drift from non-organic farms, for example, emerged as a challenge in places like California, North Dakota, Wisconsin, Indiana, Texas, South Carolina, and New York [28, 29].

An interesting challenge that may be particularly salient to farming in this region of the country relates to international competition. Specifically, given proximity to Mexico, growers in Arizona and New Mexico cited as a significant challenge the perceived competition with inexpensive produce flowing over the border. This relates both to produce shipped via Mexican growers and distributors for sale to American retailers, as well as the possible purchase and resale of Mexican produce by American farmers at farmers' markets. A third nuance of this challenge relates to Mexican companies having facilities in the US and selling inexpensive produce to American companies with which small farmers compete. One grower in southern Arizona shared:

> I could have slipped across the line and bought some produce from Mexico and taken the stickers off of it, and then I can walk into that farmers' market and I can sell it, acting as if I was the one who grew it and no one will know the difference…Other states have very rigorous regulations for farmers' markets and you are not allowed to sell something if you didn't grow it. But because Arizona [markets don't always] have those regulations, it makes it really hard for the small farmers.

Another noteworthy theme that emerged is that of a perceived challenge from governmental regulations interference. Whereas government grants and programs could be seen as a possible solution (and are viewed this way by some growers), the associated restrictions and conditions are often resented by farmers. As one farmer in Arizona said,

> It's not necessarily what you want to do with it, it's what the government wants you to do with it, and it's- what I need to do with it is what I want to do with it, not on grants for what they think I should do.

Furthermore, local farmers tend to perceive regulations as designed to favor larger farms, and the cost of optional or required certifications is often prohibitively high [27]. Being unable to afford to pay for such certifications restricts the markets to which farmers have access- and consequently limits their sales opportunities. This frustration was voiced by growers in the present study, especially in relation to food safety regulations and certifications. Several farmers in the present study either were unaware of governmental grants and programs to assist farmers, were aware of them but did not think their farms qualified for such programs, or are “vaguely, very vaguely aware that they even exist, but really don’t know how to even go about like approaching those types of programs, you know, or whatever it entails.”

Selling to specific market outlets poses unique challenges as well. For example, a challenge related to selling to larger markets for the local farmer relates to aesthetics of the product. Buyers for larger wholesale operations tend to need more of a uniform product than do those for smaller, local venues [27], a challenge noted in this study as well as in other studies. Specifically, smaller local restaurants emerged as key supporters of local foods in Arizona. One farmer shared,

> High volume restaurants you know they're not gonna be able to understand why we can't bring them the exact same sweet potatoes all the time that are all sized the same and but you know the answer is we grow four 200 foot rows of sweet potatoes each season. We don't grow a hundred acres of sweet potatoes and you know what we have to work with is much less and so you know the restaurants that get it can adjust and adapt but the restaurants that are big volume and have tons of prep people that don't really understand how to adjust when the carrots look different and sweet potatoes- you know, they're the ones who are gonna struggle.”

Perceived needs

In response to challenges, perceived needs for successful local-scale farming were described by farmers in this study. Specifically, efficiency in the form of operations and markets, food safety, good relationships with customers, and water were primary needs stated. As an example of how farmers weighed the need for efficient operations, one farmer in Arizona described the difficulty in expanding operations due to related complexities:

> We've looked into it, but the amount of our scale and the amount of hoops we'd have to jump through to do it makes it kind of counterproductive for us…So we're

> actually trying to do less markets and be more intensive in those markets that we do.

Another perceived need of farmers in Arizona and New Mexico is water. The importance of access to water and irrigation appears to be particularly salient for this region of the country, and has not been noted consistently in local farming literature from elsewhere in the country. Given the desert climates of these states, the concern about water quality, availability, and consistency can be quite serious. Several growers in New Mexico commented on recent concerns over scarcity of water.

> For instance, with the water issue right now, we have no water, no water we can't have no produce, nothing. So it's just taking a toll on us.

A common solution to the challenge of water in Arizona and New Mexico is to use irrigation as opposed to depending upon rainwater for crops. One farmer in Arizona stated,

> I mean, access to irrigation… you can't do this if you don't have access to irrigation.

Not only do farmers need to have a reliable source of water for their crops, but they also must take into consideration the type of crops that will grow in desert regions. A farmer in Arizona suggested:

> I would discourage [other farmers] from growing say alfalfa and more water-intensive [crops]. I would discourage desert and arid farmers from going to animal agriculture for the same reasons.

Perhaps related to the importance of food safety is the theme of relationships with customers. One farmer in Arizona explained that since his farm is rather small and cannot supply the same volume of the same produce every week and have it all aesthetically identical, small restaurants as opposed to large-volume ones are particularly helpful customers.

> That's why the relationship is so important. That's why I go to them and do the deliveries, meet with the chefs and see how things are going and sort of have a little more real-time feedback on things.

Even when farmers do not sell directly to the customers at a store, they still know the importance of relationship. One farmer described the importance of mechanisms for promoting local foods to build relationships.

> [The customer] really wants to eat locally, but how is she going to be able to eat locally, unless there's a way of knowing that that food is local, you know what I'm saying? And when she goes to Whole Foods she can shop there with confidence because there are pictures of the farm, you know if she asks the produce manager, the produce manager can say, "Oh yeah, [this farm] is local. Oh yeah, we like [this local farm]. Someone went out to the farm and checked them out.

The importance of the relationship with customers can even serve as a primary motivator for working as a local farmer. A grower in New Mexico commented that,

> Part of my…philosophy behind why I'm even selling food is the connection I have with the people who buy it from me.

Opportunities and perceived solutions

Although some farmers perceived grants and programs as challenges due to the time they require and constraints imposed, many farmers still choose to participate in such programs to various degrees. "Low interest loans, cash commodity crop, grants of equipment, and personal income" are some of the ways that one farmer in Arizona funds his operation. A farmer in New Mexico also commented that:

> It's a very difficult field to be in…it's easier for me because of the grants and the donations.

Farmers may need to provide evidence that they deserve financial help from some of these programs. A farmer in Arizona shared:

> They have the Women Farmers, Minority Rancher program…but it still comes down to the same things at the end. You've gotta show that it's viable and that you can repay it [the loan]. I can repay it; the question is how viable is it until you get your data that shows that you can. And you have to have some experience to be able to do that.

Another perceived solution that seems widely accepted by farmers in Arizona and New Mexico is engaging in community supported agriculture (CSA). In addition to traditional CSAs, there are related concepts emerging as viable options for sales for farmers. One farmer in Arizona used a concept related to a traditional CSA for her online "Farm Box" where customers pick and choose what they want to purchase from the farm and have it delivered to a drop-off location. Another similar idea is that of a producer cooperative, reported by one grower in New Mexico.

Market diversity and market efficiencies were two main sub-themes within the overall theme of opportunities that emerged. Examples of market diversity included selling through direct and wholesale marketing. The main reason for doing this was to increase volume of product sold by selling to different types of institutions.

Motivation

The main motivator for choosing farming as a career seemed to be rooted in its lifestyle, which reflected results of other studies [28, 194, 195]. However, it is clear that a love of farming alone is insufficient for maintaining a farming operation [35]. As such, motivators for farming were often of a non-financial nature.

The three main motivators for pursuing farming as a career reported by farmers interviewed for this study included community development, enjoyment of farming, and contributing toward a sustainable food system. As one farmer in New Mexico shared:

> The farm that I work for is not just your average farm…that sells produce just to make income; it has an educational aspect to it... their mission is something that I was very interested in and wanted to be a part of and so that's why primarily I work for this farm.

A rather unique approach to farming and community development was taken by a farmer in Arizona who is working to establish an Arizona chapter of the Farmer Veteran Coalition, currently based in Davis, California. This coalition works to mobilize veterans to work in the agricultural industry. When asked about his motivation for farming, this grower said, "education for our farmer veterans training." His concluding recommendation was to "find a farmers' market that carries the Homegrown by Heroes label and buy everything that they have."

Demonstrating an enjoyment of farming as being a primary motivator, a New Mexico farmer said, "It's not about the money, it's about waking up every morning and loving what you do." Another farmer recognized that farming was more than merely a job, saying, "I grew up this way and I'm going to keep living this lifestyle." A farmer in Arizona acknowledged some tension with this desire, though, since reality usually means that a farmer does more than just grow food. "What I want to do is farm, not farmers' markets."

In addition to enjoying farming and wanting to contribute to community development, almost half of the farmers interviewed in Arizona report wanting to contribute to a sustainable food system as one of their motivators for farming. One farmer in Arizona captured this by saying:

> The motivational factor is the opportunity to build up a vibrant and healthy local food supply system, because we need that for, just for the myriad of reasons- for the health of local economies, to bring biodiversity back into our food source, job creation, um, being able to look at sustainable ways of, on multiple platforms, of producing food, um, because you can be sustainable at different levels, it's not just about being small and being sustainable when everything else isn't, so um, I think it would be the main motivation would be being part of the solution to building up those local food supply systems.

The ideas of growing organically and sustainably seemed to go together in the minds of some farmers, as well as going back to “heritage” grains and products. One farmer seemed to feel compelled by the urgency of contributing to a healthy food system:

> What keeps me doing this is the fact that it's the only thing to be doing. I mean, there is great power and great honor in being able to produce food in a world that has lost consciousness and contact with the value of real food and our earth, and so that in a lot of ways there isn't really politically, economically, anything else I'd rather be doing.

Best Practices

Whereas traditionally farmers tend to work quite independently (due to perceived competition with other local growers), there was an emerging understanding that together local farmers can work better in the current market than alone. Some ways that this is being explored is through development of food hubs, cooperatives [27], and in northern Arizona an attempt to create a group Good Agricultural Practice (GAP) and Good Handling Practices (GHP) system. Domestically and internationally, the idea of a farmer cooperative or food hub has been encouraged by governmental grants [25]. Interest was expressed among farmers in the present study for joining together in a sort of food hub, particularly by those who enjoy farming itself and get frustrated by associated tasks that typically take small farmers' time, such as deliveries. One farmer said,

> I'm not delivering for 100 bucks worth of produce. It costs me time, you know three bucks a gallon for my diesel truck, I'm not driving all over creation for that. It's gotta have a minimum order. But if they combine all of the growers and all of the growers had certain things available, they could tell you where the demand is, they could tell you, well, we'd like you to grow this, this, this, and this, we'll grow it; we don't care. We just want to grow something.

Among some of the best practices mentioned by farmers in both New Mexico and Arizona, the importance of getting experience before starting one's own farm was repeatedly emphasized. A farmer in New Mexico summarized it well:

> Get a mentor who knows something about what you are doing. Even if you want to do it differently, he'll have basic information that will help you get through some of those pitfalls that show up early.

An Arizona farmer was a bit blunter, "Work for a farm for five years to get the nitty-gritty without starving to death." Another recommendation for success included "complete commitment, perseverance and luck."

Since labor was noted frequently as a challenge, it was hardly surprising that fair pay for labor emerged as a best practice recommended by farmers. In these regions where farming can occur year-round or nearly so, one Arizona grower recommended, "If you're looking to farm year-round, try to maintain a labor force that stays with you."

In spite of the numerous challenges experienced by local farmers, some solutions have been proposed to strengthen local food systems. For example, Clancy and Sundkvist have written about the need for a type of feedback loop that would inform consumers about where and how their food is produced- hopefully in order to spark a deeper appreciation of locally produced food that would sufficiently motivate consumers to invest in locally gown products [86, 196]. Boys and Hughes [78] called for a regional economic assessment of local food systems, and suggested that results of such studies may demonstrate the justification for further governmental investment into local food systems. Others have articulated how local food systems contribute to community economic development through social capital, conflict theory, symbolic interaction, and rational choice [197]. It is likely that a combination of these approaches will need to be fully embraced by farmers, policy makers, and customers in order to optimally support a thriving local food system nationally and specifically in the southwest of the United States.

Conclusion

Small, local farmers face numerous challenges in their profession. Many of these challenges are experienced by growers across the country and globally, whereas others appear to be more region-specific. Challenges related to access to markets, marketing, labor and capital are reported widely by farmers regardless of location. However, in this study farmers in Arizona and New Mexico also expressed challenges related to climate, water, and land, which are less often reported in the literature. As such, in order to ensure a viable future for local farmers in the southwest, it may be important to take both general and region-specific barriers and opportunities into account, especially for farms that operate on much smaller scales.

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CHAPTER 4

CARDIORESPIRATORY FITNESS AND PEAK TORQUE DIFFERENCES BETWEEN VEGETARIAN AND OMNIVORE ENDURANCE ATHLETES: A CROSS-SECTIONAL STUDY

Introduction

Vegetarian diets are increasingly being adopted for a variety of reasons including health, sustainability, and ethics-related concerns. Adherence to a vegetarian diet has been associated with a reduced risk of developing coronary heart disease [198], breast cancer [125], colorectal cancers [124], prostate cancer [123], type 2 diabetes [132], insulin resistance [127], hypertension [128], cataracts [17] and dementia [199]. Vegetarians also typically have a lower body mass index (BMI) [200] and an improved lipid profile [131]. In addition to promoting physical health, reducing or eliminating meat from the diet is environmentally advantageous since producing meat requires more land, water, and energy resources than growing plants for food [5], and producing meat creates more greenhouse gases compared to a plant-based diet [10, 13].

In spite of the many health aspects of vegetarian diets some concern has been raised pertaining to the nutrient adequacy of vegetarian diets for supporting athletic performance. Vegetarian diets are typically lower in vitamin B12, protein, creatine, and carnitine [44, 201], and iron and zinc from plant sources are less bioavailable than from meat sources [202]. However, vegetarian diets are typically higher in carbohydrate and antioxidants [203, 204], which may be advantageous for athletic performance, particularly for endurance activities [45].

Despite these issues, little research directly examining vegetarian diets and athletic performance is available. There have been mixed results regarding hypertrophic potential when comparing vegetarian diets with omnivore diets during resistive exercise training; however, in all cases these differences did not translate to differential strength gains at the completion of the trials [180, 181, 205, 206]. Adoption of a lacto-ovo vegetarian (LOV) diet for six weeks did not significantly affect endurance performance among a group of trained, male endurance athletes, in spite of a decrease in total testosterone while on the vegetarian diet [46]. There were also no group differences between 20 participants adopting an LOV diet compared to maintaining their usual omnivorous diet in terms of muscle buffering capacity in conjunction with sprint training for five weeks [47]. These studies provide some insight into the effect of a vegetarian diet on athletic performance. However, a considerable limitation in many of these studies is the inclusion of participants who typically consume meat but subsequently adopt a vegetarian diet only for the duration of the study rather than comparing participants who have adhered to a vegetarian or meat-containing diet long-term.

In a 1986 observational trial, Hanne and colleagues compared athletes who had maintained either an LOV or omnivore diet for at least two years and found no group differences for aerobic or anaerobic capacity [63]. However, aerobic capacity was estimated using cycle ergometry and predicted VO2 max, and strength or torque were not measured. Moreover, body adiposity was estimated using skinfold thickness. Given the current interest in vegetarian diets, in terms of both long-term health and environmental benefits, it is important to reaffirm, using leading-edge technology, that high-level athletic performance is supported by these diets.

The purpose of the present cross-sectional study was to examine body composition and performance measures in vegetarian and omnivore adult endurance athletes who had adhered to their respective diet plans for at least three months. Body composition, including visceral adiposity, was measured using dual-energy X-ray absorptiometry (DXA), leg strength was measured using a dynamometer, and aerobic capacity was determined using the Bruce protocol treadmill test. It was hypothesized that there would be no differences between groups on any parameters.

Materials and methods

Participant recruitment

Healthy men and women, both vegetarians and omnivores, were recruited through advertisements on Stevebay.org (a popular website for endurance athletes), Facebook, and through word of mouth. Participants were either on a competitive club sports team at a National Collegiate Athletic Association (NCAA) Division 1 university or training for a major endurance race (such as a marathon, triathlon, cycling race, or other ultra-endurance event). An equal number of omnivore and vegetarian athletes were enrolled in the study between the ages of 21–58 years (35 per group); however, answers to diet questions indicated that eight of the vegetarians ate meat on occasion, and these subjects were reclassified as omnivores. Participants completed a health history questionnaire and were excluded if they had any chronic disease. All participants had the study verbally explained to them and provided their written consent; this study was approved by the Institutional Review Board at Arizona State University, number HS1211008557. Study recruitment and all study measurements took place between August and November 2015.

Experimental approach

In this cross-sectional investigation participants completed all study measurements in a single visit. Prior to the visit, participants completed a seven-day food log. Fifty-seven out of seventy participants returned completed food logs, all of which were used in dietary analysis using Food Processor SQL Nutrition and Fitness Software by ESHA Research, Inc. (version 10.11.0, Salem, OR). Height and body mass were measured using a SECA directprint 284 digital measuring station when participants were wearing light clothing and no shoes. Participants also completed a full-body DXA scan (Lunar iDXA, General Electric Company, East Cleavland, OH, USA), which was conducted by a certified radiology technologist.

Maximal oxygen uptake was determined by following the Bruce protocol [207] on a Trackmaster TMX425C treadmill using the Parvo Medics TrueOne 2400 (Sandy, UT, USA) metabolic measurement system. Prior to beginning the test, participants were instructed how to report their fatigue level using the Borg rating of perceived exertion (RPE) scale [208]. When asked by a research assistant, they reported their RPE at the end of each minute of the test by pointing to a printed Borg RPE chart being held by a research assistant. Participants were verbally encouraged by the research team to push as long as they could and to try to reach a true maximal effort. Handrail support was not allowed during the test. Maximal respiratory exchange ratio (RER) was recorded to help determine whether subjects had reached a "true" maximal effort during the test. Maximal RER values of ≥ 1.1 were considered indicative of true maximal oxygen uptake [209, 210]. Peak oxygen uptake reported is the highest oxygen uptake measured during the test.

Finally, participants completed a series of leg extensions and flexions on the HumacNorm isokinetic dynamometer (Computer Sports Medicine Inc. (CSMi, Stoughton, MA, USA) at 60 degrees per second (d/s), 180 d/s, and 240 d/s. Participants were familiarized with the protocol and conducted one practice repetition at each speed prior to performing three maximal effort repetitions at each speed. All sets, including practice repetitions, were performed on both legs, and self-reported dominant side was recorded. Participants moved from the VO2 max test immediately into the dynamometer testing, and there were 30 s of rest between sets on the dynamometer.

Statistical analyses

Based on the data of Hanne et al. [27], at 80% power and an alpha level of 5%, 15 participants per group would be needed to detect a 10% difference in strength and 80 participants per group would be needed to detect a 10% change in aerobic capacity between groups. Data were analyzed for normality and log transformed if necessary, and outliers (values > 3 standard deviations (SD) from the mean) were removed prior to data analyses. Data reported are the mean ± SD, and participant characteristics are displayed by gender and diet group. A 2-way analysis of variance (ANOVA) analysis was used to determine differences between diet groups for participant characteristics followed by an independent *t*-test for post-hoc examination by diet within gender if indicated. Dietary data are reported by group, and a general linear model analysis was used to examine differences between groups controlling for gender. Data were analyzed using the Statistical Package for Social Sciences (SPSS) 23.0 for Mac (SPSS, Inc., Chicago, IL, USA).

Results

In the vegetarian group, 24 of the 27 participants (89%) had adhered to a vegetarian diet for >2 years. Of the remaining three participants, the diet had been followed for three, six, or eleven months. Fifteen of the vegetarians were vegans (nine men and six women), and twelve were lacto-ovo vegetarians (five men and seven women).

There were no significant age or gender differences between groups (Table 1). Significant differences were noted between diet groups for body mass and for lean body mass (LBM): female vegetarians tended to have a lower total body mass and LBM compared to the female omnivores (−11% and −7% respectively). Adiposity, however, did not differ between diet groups. Physical activity levels, recorded as $kcal \cdot kg^{-1} \cdot week^{-1}$, were 20% higher for vegetarians compared to omnivores ($p = 0.018$) (Table 1). Maximal oxygen uptake (mL/kg/min) differed significantly between diet groups, and post-hoc analyses revealed a significantly greater aerobic capacity in the female vegetarians in comparison to the female omnivores (+13%, $p < 0.05$) (Table 1); however, absolute maximal oxygen uptake (L/min) did not differ between diet groups. Peak torque when doing leg extensions was not different between diet groups. The 7-day diet records revealed several differences in nutrient intake between diet groups. Although total energy intakes were similar between the diet groups, the vegetarians consumed more carbohydrate, fiber, and iron daily compared to omnivores (Table 2). However, daily intakes for protein, saturated fat, cholesterol, vitamin B12, and selenium were lower among the vegetarians in comparison to the omnivores.

Table 1. Participant characteristics by diet group (vegetarian, VEG; omnivorous, OMN) [1].

	VEG		OMN		***p***
Measure	**Male (14)**	**Female (13)**	**Male (26)**	**Female (17)**	
Age, year	36.1 ± 10.2	36.7 ± 7.7	38.0 ± 10.0	37.1 ± 8.7	0.608
Body mass, kg	73.3 ± 14.8	58.3 ± 7.6 **	78.0 ± 11.0	65.4 ± 11.6	**0.043**
BMI, kg/m^2	24.0 ± 4.4	21.8 ± 2.5	24.8 ± 2.6	23.5 ± 3.8	0.123
Lean mass, kg	56.3 ± 7.4	42.0 ± 4.9 **	60.2 ± 7.3	45.4 ± 5.1	**0.026**
Waist, cm	81.6 ± 10.7	69.0 ± 14.8	85.2 ± 7.4	73.8 ± 8.2	0.093
Body fat, %	19.2 ± 6.5	25.5 ± 4.2	19.2 ± 6.4	26.9 ± 8.1	0.659
Visceral fat, cm^3	447.4 ± 419.8	110.4 ± 123.0	538.5 ± 404.3	206.4 ± 254.6	0.656
METS, $kcal \cdot kg^{-1} \cdot week^{-1}$	108.8 ± 32.9	106.1 ± 36.6 **	91.7 ± 33.2	85.6 ± 20.8	**0.018**
VO_2max, mL/kg/min	62.6 ± 15.4	53.0 ± 6.9 *	55.7 ± 8.4	47.1 ± 8.6	**0.011**
VO_2max, L/min	4.44 ± 0.81	3.21 ± 0.67	4.29 ± 0.59	3.03 ± 0.49	0.295
Peak torque, ft-lbs	114.4 ± 26.2	65.5 ± 12.8	124.2 ± 24.5	73.6 ± 18.6	0.104

[1] Data are the mean ± SD; n in parentheses; gender distribution did not differ by diet group ($p = 0.460$; Chi Square analysis). *p* for 2-way ANOVA analyses by diet (non-normal data transformed prior to analysis (visceral fat)). The single asterisk (*) indicates significant difference within gender by diet group ($p < 0.05$); the double asterisk (**) indicates a trend for difference within gender by diet group ($0.05 < p < 0.10$).

Table 2. Nutrient differences by diet group (vegetarian, VEG; omnivorous, OMN) [1].

	VEG (22)	**OMN (35)**	***p***	**Reference Range [2]**
Total kilocalories (kcal)	2443 ± 535	2266 ± 612	0.072	-
Carbohydrate (CHO) (g)	328 ± 70	248 ± 101	**0.001**	-
CHO (% energy)	53 ± 6	48 ± 7	**0.010**	45%–65%
Fiber (g)	38 ± 13	24 ± 9	**<0.001**	38/25 g [M/F]
Protein (g)	78 ± 19	101 ± 35	**0.006**	-
Protein (% energy)	12 ± 2	17 ± 4	**<0.001**	10%–35%
Protein (g/kg body mass)	1.2 ± 0.3	1.4 ± 0.5	0.220	0.8 g/kg
Fat (g)	90 ± 26	83 ± 33	0.901	-
Fat (% energy)	32 ± 5	32 ± 6	0.952	20%–35%
Saturated fat (g)	22.8 ± 11.2	25.7 ± 10.1	0.207	-
Saturated fat (% energy)	8.3 ± 3.1	11.6 ± 6.3	**0.002**	<10%
Cholesterol (mg)	102.8 ± 119.5	301.2 ± 165.6	**<0.001**	-
Vitamin C (mg)	117.0 ± 64.0	83.0 ± 46.5	0.076	90/75 mg [M/F]
Vitamin D (IU)	115.4 ± 111.4	129.0 ± 115.5	0.201	600 IU
Vitamin B12 (mcg)	3.0 ± 3	4.8 ± 4.6	**0.006**	2.4 mcg
Selenium (mcg)	41.8 ± 36.0	62.6 ± 33.6	**0.002**	55 mcg
Sodium (mg)	2931.2 ± 783.1	2972.8 ± 887.5	0.794	<2300 mg
Iron (mg)	19.4 ± 7.8	15.4 ± 5.4	**0.017**	8/18 mg [M/F]
Zinc (mg)	8.5 ± 9.1	8.9 ± 4.9	0.149	11/8 mg [M/F]
Calcium (mg)	971.0 ± 401.6	878.1 ± 314.9	0.378	1000 mg
Phosphorus (mg)	782.0 ± 378.0	831.2 ± 336.4	0.507	700 mg
Omega-3 fatty acid (g)	1.6 ± 2.5	0.9 ± 0.7	0.326	-
Omega-3 fatty acid (% energy)	0.004 ± 0.005	0.004 ± 0.003	0.613	0.6%–1.2%
Omega-6 fatty acid (g)	7.7 ± 5.4	6.1 ± 4.4	0.145	-
Omega-6 fatty acid (% energy)	2.8 ± 1.6	2.4 ± 1.3	0.358	5%–10%

[1] Data are the mean ± SD; sample size in parentheses. *p* for general linear model analyses (non-normal data transformed prior to analysis (all variables except carbohydrate variables and fat percentage) and 2 outliers (VEG group) removed prior to analysis for saturated fat); [2] Reference ranges are the Recommended Dietary Allowance or the Acceptable Macronutrient Distribution Range; note the American College of Sports Medicine recommends that athletes consume 1.2–2.0 g protein/kg body mass.

Discussion

Results from this study indicate that compared to their omnivore counterparts, vegetarian endurance athletes have comparable strength as indicated by leg extension peak torque, and possibly a greater degree of aerobic capacity, particularly in females, as indicted by a progressive maximal treadmill test to exhaustion. Dietary intake on several key nutrients differed considerably between groups. Some, but not all, results are consistent with previous reports.

Our study is significant for its increased rigor in measurement assessments compared to previous comparisons of vegetarian and omnivore athletes. We determined maximal oxygen uptake by a graded test to exhaustion on a treadmill instead of predicting VO2 max using a cycle ergometer, as recommended by Shepard and colleagues [211]. Additionally, we measured body composition using a DXA scan, currently regarded as the clinical gold standard for body composition assessment, instead of skinfolds [212]. Finally, we assessed both athletic performance and nutrient intake differences between vegetarians and omnivores, whereas most previously published studies focus exclusively on one of these areas.

Body mass and BMI

Like other studies of vegetarians in the general population, vegetarian participants in the present study had significantly lower body mass compared to omnivores [200, 213]. This is in spite of the fact that our study included participants engaged in considerable endurance activities, which could be very different in multiple ways from the general population. One prior study in athletes, conducted by Hanne et al. compared vegetarians and omnivores anthropometrically and found no significant differences between groups for weight [63]. It is noteworthy that the athletes in the Hanne et al. study included football, basketball, and water polo players in addition to endurance athletes.

Lean body mass

LBM was significantly lower for the vegetarian athletes compared to their omnivore counterparts, a difference which was most prominent among the female participants with female vegetarian athletes possessing 7% less LBM as compared to the female omnivore athletes. In spite of this, there were no significant differences in body fat percentage or BMI between groups. To our knowledge, this is the first study to examine lean body mass differences between vegetarian and omnivore athletes. It is important to note, however, that this difference in lean body mass did not translate into differential peak torque on the leg extension.

Although other studies have not assessed lean body mass of vegetarian athletes specifically, Campbell and colleagues compared resistance-training induced changes in lean body mass and strength between groups assigned to either an omnivorous diet or a lacto-ovo-vegetarian diet for the duration of the study and found that, in spite of differential lean body mass gains, the two groups increased strength similarly [180]. Conversely, a 12-week training study by Haub and colleagues showed no significant differences in strength, body composition, or muscle cross-sectional area between groups assigned to either a lacto-ovo-vegetarian or beef-containing diet.

Body fat percent and visceral adipose tissue (VAT)

Contrary to the female vegetarian athletes in Hanne's group, no significant differences in body fat percentage were found between vegetarian and omnivore athletes in this study. Additionally, there were no significant differences between groups for visceral adipose tissue (VAT). Participants in the present study had VAT values above those reported for similar aged healthy lean sedentary adults (~250 cm^3), both omnivores and vegetarians [214, 215], but lower than those noted for older adults (1000–1560 cm^3) [216]. Although there are no standard reference ranges for VAT, values near 1000 cm^3 were associated with BMI values near 25 kg/m^2 and values > 300 cm^3 have been suggested as predictive of risk for metabolic syndrome in young adults [215, 216]. As technology permitting quantification of visceral adipose tissue is relatively new for research purposes, this study contributes to the emerging literature by providing VAT values for athletes. VAT and BMI are strongly correlated in this study (r = 0.742), a factor that may be important for estimating VAT inexpensively without a DXA scan.

VO2 max

Unlike athletes in Hanne's study, vegetarians in the present study had significantly higher maximal oxygen uptake than their omnivore counterparts [63]. This difference was most predominant in the female participants with a 13% greater VO2 max score for the female vegetarians as compared to the female omnivores, but this difference was not observed for absolute VO2 max (L/min), which suggests that body weight factored into this difference. This gender difference is intriguing and merits further investigation in future studies. One potential reason that athletes in the present study had higher VO2 max values than those in Hanne's study may be due to the difference between cycle ergometry and treadmill testing methods. However, it is possible that the athletes in our study simply were more trained and that diet effects on differences in VO2 potential emerge only at higher levels of fitness.

Other work that contributes to our understanding of aerobic and anaerobic performance differences by diet include the study of Hietavala et al. that found no significant difference in time to exhaustion (albeit a higher oxygen uptake at a given percent of maximal oxygen consumption) between participants following a low-protein vegetarian diet compared to a mixed diet [174]. Subjects in this study adhered to the low protein vegetarian diet (0.80 ± 0.11 g of protein per kilogram of body mass (g/kg) vs. 1.59 ± 0.28 g/kg on their normal diet) for four days before being tested on a cycle ergometer. As this study did not use participants who practiced vegetarianism outside of the study, and the amount of protein that subjects were allowed to consume on the vegetarian diet was restricted, true differences between vegetarians and omnivores may not be evident. Baguet et al. found no differences in repeated sprint ability between participants following a vegetarian or mixed diet for five weeks; again, these subjects were not following a vegetarian diet long-term [47]. Raben et al. found no differences in maximal oxygen uptake among subjects after adoption of a lacto-ovo vegetarian diet for six weeks [46]. However, the major disadvantage of interpreting results of these studies for vegetarian athletes is that participants in these studies only adhered to a vegetarian diet briefly for the duration of the study.

Peak torque

Similar to the Hanne et al. study that compared the power output of vegetarian and omnivore athletes [63], we found no significant differences by diet in terms of peak torque using leg extensions. Other studies in untrained older men that have examined strength development over time in response to a training program have found mixed results when comparing participants following a vegetarian or mixed diet [180, 206]. This is noteworthy, particularly since strength and lean body mass were strongly correlated (r = 0.764) in the present study, as well as the fact that omnivores had significantly more lean body mass vs. the vegetarians. A nonsignificant trend for omnivores to produce higher peak torque is observed, however. It is conceivable that the omnivore diet pattern may be preferred for sports that rely on greater lean mass, and subsequently peak torque. To further investigate this, future work ought to examine if strength can be increased similarly by vegetarian and omnivore athletes engaged in strength training (not just by participants following a vegetarian diet for a few weeks).

Nutrient intake

Nutrient intake was calculated from food and beverage intakes only and did not include any supplements. There were no significant differences in caloric intake or total fat intake between vegetarians and omnivores. However, vegetarians reported significantly more dietary carbohydrate (both in terms of absolute intake and as a percent of daily calories), fiber, and iron intake. Omnivores consumed more dietary protein (both in terms of absolute intake and as a percent of daily calories), saturated fat, cholesterol, and vitamin B12.

However, when expressed relative to body mass, there were no differences in dietary protein intake.

That vegetarians and omnivores in the present study did not differ in terms of caloric intake is consistent with findings by Janelle and Barr from their comparison of 45 vegetarian and omnivore women [44], yet it is in contrast to results from Calkins and colleagues who compared 50 vegetarians, vegans, and omnivores. They found vegetarians consumed about 200 fewer kcal than omnivores [204]. These studies were both in the general population, not specifically with athletes. Calkins et al. also reported that omnivores consumed more fat than vegetarians, a fact that partially contributed to the higher caloric intake. This too is in contrast to the findings in the present study which found no significant difference either in grams of fat consumed or the percent contribution of fat to the daily calorie intake, even though saturated fat was significantly higher in omnivorous diets. Other studies involving the general population have also reported omnivores eating more energy and total fat than vegetarians [42, 200, 217, 218].

Higher carbohydrate (when expressed either as an absolute amount or as a percent of total daily calories) and fiber intake among vegetarians in comparison to omnivores in the present study is consistent with findings in other studies [42, 200, 218-221]. As these studies have been conducted in the general population, the present study contributes to the literature by demonstrating that this dietary pattern can be extended to endurance athletes as well. One study by Janelle and Barr stands in contrast to these findings, as they did not find significant differences in carbohydrate or fiber intake between vegetarian and omnivore women; those participants were not athletes [44]. That vegetarians in the present study consumed more carbohydrates than omnivores is notable since they are all athletes, and the importance of carbohydrates for exercise is well-established [150, 222, 223].

Like the present study, other studies have also reported that vegetarians consume less protein (both absolute intake and as a percent of the daily calories) [42, 44, 200, 219] and vitamin B12 [217, 224] than omnivores. Our study contributes to the literature since other reports have been in the general population instead of within athletic groups. Of note, though, differences in dietary protein intake are not significant when expressed relative to body mass, which is typically the preferred method for recommending protein for athletes [150]. Nonetheless, dietary protein intake was weakly correlated with peak torque (r = 0.359, p = 0.006) in the present study, and dietary protein intake was moderately correlated with lean body mass (r = 0.415, p = 0.001). Expectantly, lean body mass was strongly correlated with peak torque (r = 0.764, p < 0.001). Hence, it is conceivable that protein intake could influence strength if intakes had been inadequate. In the present evaluation, protein intakes in the vegetarian participants averaged 1.2 g/kg body mass, which falls in the recommended range for athletes [150, 166].

There are conflicting findings in the rest of the literature regarding whether omnivores or vegetarians consume more iron. The Wilson et al. study of vegetarian men found that vegetarians consumed more iron [218], but Ball and Bartlett reported no difference in dietary iron intake between female vegetarian and omnivores [225]. Clary et al. compared 1475 vegans, vegetarians, semi-vegetarians, pescetarians, and omnivores and also showed that vegetarians consume more iron than omnivores [42]. Although vegetarians consumed more iron than omnivores in the present study, iron bioavailability was likely reduced as has been shown in other trials [202]. Dietary intakes of zinc did not vary by diet group herein, but generally the literature suggests that vegetarians consume somewhat less dietary zinc than omnivores [44, 226-228]. The lower intakes of selenium by vegetarians in comparison to omnivores has also been reported by others and reflects the low levels of selenium in plant foods relative to flesh foods [173, 229].

Limitations

In addition to the small sample size, limitations to the study include the variable level of experience of the athletes for their respective sports, and related fitness levels. Although most participants were training for and competing in races such as marathons, Ironman-distance triathlons, and competitive cycling, there were a few participants who were training for shorter distance races. However, this variation makes results more generalizable to athletes of various fitness levels.

Future directions

Future work is needed to compare vegetarian and omnivore endurance athletes' performance on events more similar to actual sporting events (such as time trials or peak power on a cycle ergometer) and probe differences by type of vegetarian diet (lacto-ovo vegetarian or vegan). Additional work is needed to explore the adequacy of long-term adherence to vegetarian and vegan diets for supporting development of lean body mass.

Conclusions

Our cross-sectional comparison of vegetarian and omnivore adult endurance athletes shows higher maximal oxygen uptake values among vegetarians and comparable strength, in spite of anthropometric and dietary differences. This study suggests that following a vegetarian diet may adequately support strength and cardiorespiratory fitness development, and may even be advantageous for supporting cardiorespiratory fitness. Certainly many factors affect an athlete's sports performance, and there is no dietary substitute for quality training. However, our study contributes to the literature about cardiorespiratory and strength comparisons between vegetarian and omnivore endurance athletes, and may provide a rationale about the adequacy of vegetarian diets for sport performance. As this was a small cross-sectional study using endurance athletes, larger intervention trials are necessary to bolster conclusions about adequacy of vegetarian diets to support performance in strength and power-focused sports.

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CHAPTER 5

MUSCLE GROWTH AND STRENGTH DEVELOPMENT FOLLOWING A 12-WEEK RESISTANCE TRAINING PROGRAM: A COMPARISON BETWEEN CONSUMING SOY AND WHEY PROTEIN SUPPLEMENTS MATCHED FOR LEUCINE CONTENT

Introduction

Plant-based diets and plant protein have been gaining in popularity in recent years for a number of reasons including health and environmental benefits [142]. Documented health benefits from following a vegetarian diet include a reduced risk of certain types of cancers [123-125], insulin resistance [127], type 2 diabetes [132], hypertension [128] and an improvement in lipid profile [131]. And from an ecological perspective, reducing or eliminating consumption of animal-derived foods generally results in much-reduced demands on ‘ecosystem services,’ including land, water, phosphate, and energy resources [5, 136]. Production of meat in particular emits more greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, compared to a vegetarian diet [10, 13]. As such, even occasional dietary ‘protein flips’ from animal to plant protein [9], rather than wholesale adoption of a strictly vegetarian diet, can still result in reduced environmental impact.

Protein supplementation is an aspect of dietary intake in which such ‘flips’ could occur. But changes such as these can have important implications, especially for those supplementing in relation to athletic performance. Soy and whey protein, for example, both represent complete proteins and are frequently used as examples of plant-based and animal-based protein in research. However, soy and whey differ in terms of amino acid profile, digestibility, and the kinetics of their absorption. Soy protein, compared to whey, contains a lower amount of essential amino acids (EAAs) on a per gram basis, and notably fewer branched-chain amino acids (BCAAs) [145]. Such differences are important to athletic performance as muscle protein synthesis can be regulated to a great degree by consumption of EAAs [162]. In particular, BCAAs increase muscle protein synthesis while simultaneously decreasing the rate of muscle protein breakdown by influencing key signaling pathways [163]. Although mechanisms have yet to be fully described, leucine plays a particularly critical regulatory role in muscle protein synthesis, stimulating multiple signal transduction pathways that help control mRNA translation leading to an upregulation of skeletal muscle protein synthesis [55, 164].

Both soy and whey are also considered high quality proteins based on similarly high Protein Digestibility Corrected Amino Acid Scores (PDCAAS) and Digestible Indispensable Amino Acid Scores (DIAAS) [155, 230, 231]. Nonetheless, soy protein performs less well in stimulating acute post-exercise muscle synthesis compared to whey or milk protein when ingested on an isonitrogenous basis [148, 189, 232]. This may be due in part to soy protein being used to synthesize urea to a greater extent than whey protein [233], possibly because of the lower essential amino acid content [145].

Similarly, chronic resistance exercise training (RET) studies comparing soy and whey protein supplementation have yielded mixed results on anabolic responsiveness. A nine-week study that included consuming either soy or whey protein bars (11 grams of protein each) three times per day in conjunction with a strength training routine found no significant differences between protein groups for increasing lean body mass compared to a group not receiving any supplement [183]. Candow and colleagues also found no significant differences in lean body mass or strength changes between groups supplementing with either 1.2 grams of whey or soy protein per kilogram of body mass (g/kg) in conjunction with resistance training over six weeks [51]. However, Hartman and colleagues found that consuming skim milk (which contains whey) post-exercise for five weeks contributed to greater type II muscle fiber area and fat-free mass increases compared to a group consuming isonitrogenous (~17.5 g) fat-free soy protein [53]. Additionally, Volek and colleagues conducted a nine-month training intervention that found subjects supplementing with whey protein had greater lean body mass gains than a group supplementing with soy protein matched for total protein; differences in lean body mass accrual, however, did not translate to increased strength gains for the whey group compared to the soy group [54].

These studies, while important in advancing understanding of the impacts of soy versus whey supplementation in relation to resistance training, are based primarily on matching protein sources nitrogenously. Given the critical role of leucine in muscle anabolism, however, the question remains as to whether soy versus whey protein intake matched for leucine content might elicit different outcomes. To address this gap in the literature, this study examined the impact of soy versus whey protein supplement intake matched for leucine content on lean body mass and strength in conjunction with a 12-week strength training program.

Methods

Study design

A prospective, 2-group parallel-arm, randomized, double-blind study was conducted to compare the impact of soy or whey protein isolate supplements on strength and lean body mass changes in response to resistance training. Participants were randomly assigned to receive either 19 grams of whey protein isolate or 26 grams of soy protein isolate daily. Both protein supplements contained two total grams of leucine. This amount of leucine was targeted for consumption as 10 grams of EAA (including ~1.8 g leucine) has been shown to be sufficient to maximally stimulate MPS in young men and women (about age 30), and that additional leucine (3.5 g) does not further augment MPS response [61].

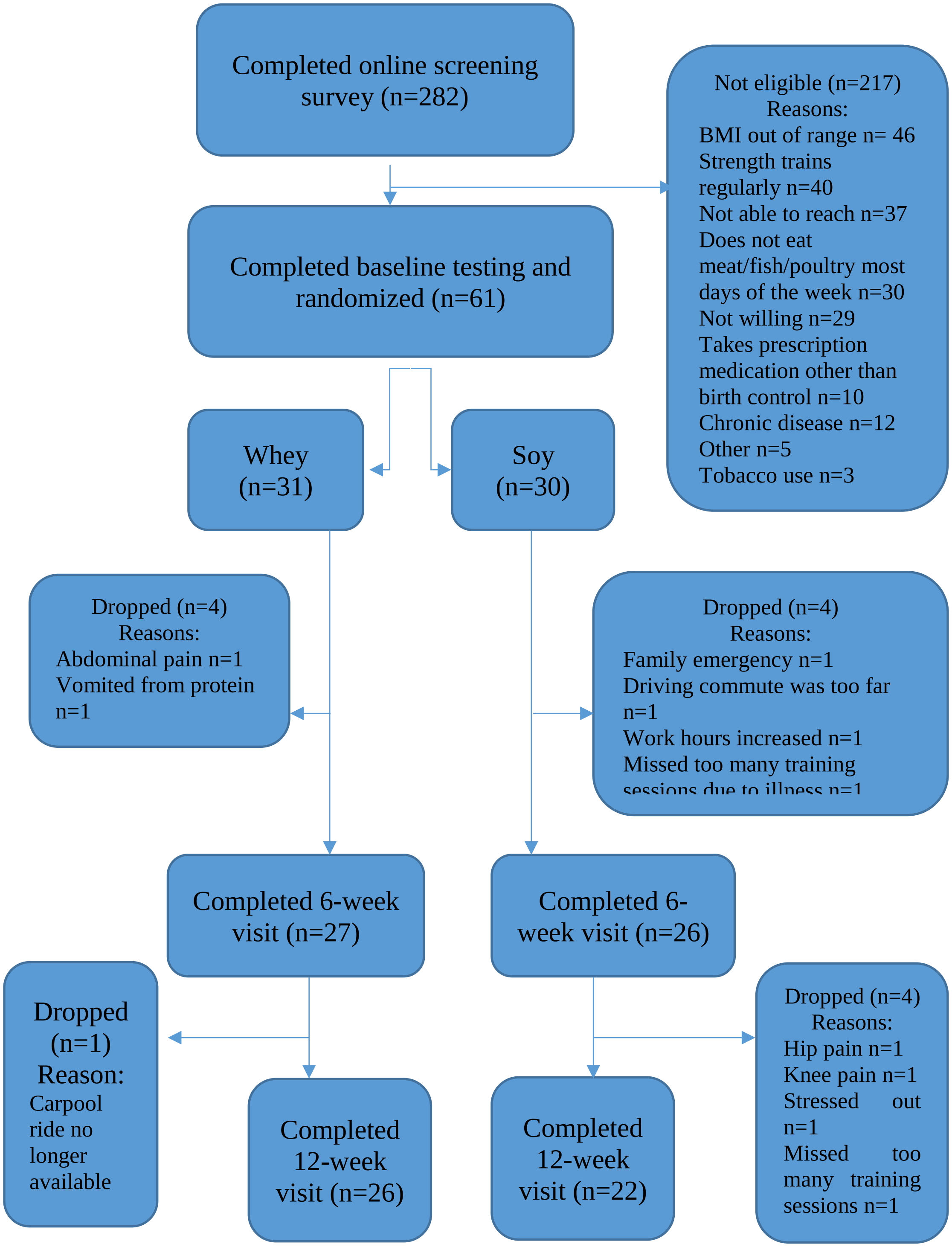
Randomization was based upon baseline visit measurements for body mass index (BMI), leg extension peak torque, and lean body mass. Participants and all investigators except one were blinded to the group assignment; the principal investigator collecting data was blinded to group assignment. Participants engaged in supervised strength training sessions three nonconsecutive days per week for 12 weeks and consumed their assigned protein powder supplement daily for the duration of the study. Body mass; body composition; vastus lateralis, vastus intermedius, and subcutaneous adipose tissue thickness; and peak torque when doing leg extensions and flexions on an isokinetic dynamometer were determined at baseline, after six weeks, and after 12 weeks.

Subjects

Participants were healthy, nonsmoking males and females with a BMI between 18.5 and 29.9, ages 18-35 years who were recreationally active but had not participated in structured weight training for at least the previous 12 months and did not have a change in body weight of more than 10 pounds in the previous three months. Females were not pregnant or lactating, nor were they within six months postpartum. Exclusion criteria included adherence to a vegetarian or vegan diet, having any chronic disease, use of tobacco products, pregnancy or intention to become pregnant in the next 12 weeks, allergy to whey or soy, and any musculoskeletal injury or condition that would preclude full participation in a new exercise program. Assuming 80% power at an alpha level of 5%, it was determined that 20 subjects were needed per group (40 subjects total) to determine a difference of 1 kilogram (kg) lean body mass (LBM) between groups.

Two hundred eighty-two people responded to the screening survey online from August 2016 through January 2017 (see Fig. 1). Most survey respondents did not meet inclusion requirements or failed to reply to an email invitation to come in for a baseline lab visit. Sixty-one participants completed informed consent documents, were randomized, and began training. The study was approved by the Institutional Review Board at ASU (STUDY00004456), and all subjects provided written informed consent after having the study purpose and possible risks explained to them.

Figure 1. CONSORT flow chart



Dietary protocol

Participants were clearly instructed to maintain their usual diet and physical activity level through the duration of the study. Trainers regularly reminded participants of the importance of this at each training session. Three times during the study (baseline, midway through the study, and during the 12^{th} week of the intervention) participants completed three-day food logs (two weekdays and one weekend day). They were instructed by a Registered Dietitian on how to complete the food logs completely and of the importance in being detailed and accurate in their records, including brand names when possible and precise amounts of each food, beverage, and condiment. All diet records were entered into ESHA Food Processor by the same person to ensure standardization. Total kilocalories, grams of protein, and percent contribution of macronutrients were compared within participants and between group means to ensure that participants did not significantly change the composition of their diets during the intervention.

Supplement protocol

The protein supplement was taken daily and mixed with water. Participants were permitted to mix a non-nutritive sweetener with their protein if they wished, but clearly instructed that they were not to mix it with milk or any other food substances or calorie-containing beverages. Furthermore, the protein was to be taken between meals, rather than concurrently with other food as the timing of protein consumption is an important factor in addition to amount of protein being consumed for maximizing the 24-hour muscle protein factional synthesis rate. Specifically, consuming an even distribution of protein throughout the day instead of in skewed amounts promotes better protein synthesis [167]. Furthermore, protein in conjunction with or instead of carbohydrate alone post-exercise augments muscle protein synthesis and minimizes muscle protein breakdown [234].

Protein powder was measured to the nearest gram using a MyWeight KD-8000 digital food scale. Daily protein was measured into individual plastic bags so that the participant would take one bag of protein powder and mix it with water in a provided shaker bottle each day. At the start of the study, the participant was provided with a large bag containing 84 individually portioned bags of protein powder, which was enough to take one bag of protein daily for the 12-week study. Protein supplements were either Perham whey protein powder isolate or Solae soy protein powder isolate. Leucine content of the products was determined from the USDA Nutrient database for soy protein isolate and from an analysis by Bongards for whey protein isolate since a product-specific analysis was available. Amino acid profile of each supplement is displayed in Table 1.

Table 1. Amino acid composition of protein supplements.

Nutrient	Whey Protein Isolate (21 g)	Soy Protein Isolate (29 g)
Protein (g)	19	26
Amino acid composition (mg)		
Leucine	2008	1967
Isoleucine	1230	1233
Valine	1041	1188
Histidine	300	668
Lysine	1847	1545
Methionine	417	328
Phenylalanine	576	1332
Threonine	1293	910
Tryptophan	360	324
Arginine	420	1934
Glutamic acid	3287	5061
Cystine	4567	303
Alanine	984	1041
Glycine	307	1045
Proline	1167	1438
Serine	835	1332
Tyrosine	560	934
Aspartic acid	2038	2959

Resistance training protocol

The resistance training program targeted muscles in the whole body in a progressive manner over the intervention. Participants completed three workouts per week, each separated by at least 48 hours. Each workout began with an easy, self-selected five-minute warmup on either the treadmill, elliptical, or stationary bike. Exercises included barbell bench press, incline chest press using a barbell, leg press, seated leg curl, leg extension, lat pull down, upright row, and abdominal exercises. Participants rested for 1-2 minutes between each set. The first workout of the week was not intended to take participants to complete muscular failure. However, the other two workouts per week were intended to elicit complete voluntary muscular failure. Weeks 1-6 entailed lifting three sets of 10 repetitions at 60% of participants' one-repetition maximum (1-RM) for all exercises on the first workout of the week. The second and third workouts entailed lifting three sets of about 10 repetitions at about 70% of their 1-RM for each exercise. The precise weight lifted was increased as needed in order for participants to be completely fatigued by about repetition 10, even if that meant lifting higher than 70% of the observed 1-RM. Weeks 7-12 involved doing the same exercises but at a higher intensity. The first workout of each week was four sets of eight repetitions at 70% of the 1-RM. One-repetition maximum weight lifted was recalculated during the first workout of weeks 1, 4, 7, and 10 for the bench press, leg press, and knee extensions. The second two workouts of the week were also four sets of eight repetitions, but at 80% of the 1-RM. As with the first half of the training program, the actual weight lifted was increased above 80% of the measured 1-RM if needed in order for the participants to be completely fatigued after about repetition eight.

Testing protocol

After obtaining written informed consent at the baseline visit, participants' height and weight were measured using a SECA directprint 284 digital measuring station. Participants voided their bladders prior to being weighed and all females completed a pregnancy test before a dual x-ray absorptiometry (DXA) scan (Lunar iDXA, General Electric Company, East Cleavland, OH, USA) to ensure that they were not pregnant. Participants laid down for 15 minutes to normalize fluid shifts prior to undergoing the DXA scan. All scans were completed by the same certified radiology technician.

Participants remained supine following the 15 minutes of rest while an ultrasound of each participant's self-identified dominant leg's quadriceps was conducted using a uSmart 3300 (Terason, Burlington, MA) ultrasound machine with a 15-4 Mhz linear transducer at 56% of the length from the greater trochanter of the femur to the lateral epicondyle. Circumference of the leg at this location was also measured. Muscle thickness of the vastus lateralis and vastus intermedius was measured using ImageJ software for Mac and assessed as the thickness from the superficial aponeurosis to the femur. The same researcher completed all ultrasound measurements.

Lastly, participants completed two sets of leg extensions and flexions on an isokinetic dynamometer (Computer Sports Medicine Inc. (CSMi), Stoughton, MA, USA) at 60 degrees per second (d/s) on their self-reported dominant leg in order to determine peak torque in this motion. This speed was selected due to its prevalence in isokinetic dynamometry literature [235]. Participants were seated and secured on the dynamometer using shin, thigh, pelvic, and upper torso stabilization straps. The knee joint was aligned with the axis of the dynamometer, and a range of motion of 0-90 degrees was targeted for all participants. After having the testing protocol explained to them, participants completed the first set of three repetitions, intended to orient the participant to the exercise on the machine, and they were instructed not to exert full force. After a brief rest, they were instructed that the second set of three repetitions should be completed with maximal effort.

The same assessments, except for measuring height, occurred at the second visit (midway through the study, after six weeks of training) and post-intervention (after 12 weeks of training). Participants were assigned to a trainer to oversee each strength training session. The trainer was also charged with reminding the participants to consume their protein daily and to help ensure participant retention. On workout days the trainer observed the participant consume the protein powder for added accountability. One cohort completed the intervention during the fall semester of 2016 and a second cohort completed the intervention during the spring semester of 2017. Analyses were completed after all participants in both cohorts completed the study. In order to be included in analyses, participants could not have missed more than three training sessions in 12-weeks (that is, they must have completed >92% of sessions).

Primary outcomes of interest in this study were changes in lean body mass and strength as assessed by peak torque when doing leg extensions and flexions on an isokinetic dynamometer at 60 d/s. Particularly, we were interested to see if there was a difference between groups in changes over time. Secondary outcomes included changes in body composition, bone mineral density, and muscle and subcutaneous adipose tissue thickness over time. Body composition was measured through a DXA scan, peak torque values were reported through the dynamometer's output, and muscle and subcutaneous adipose tissue thickness were assessed via ultrasound.

Statistical analyses

Data were assessed for normality and transformed using log10 transformation (lean body mass, peak torque for leg extensions, visceral adipose tissue, and bone mineral density) or square root transformation (peak torque for leg flexions) if necessary to achieve normality. Age was not able to be normalized and baseline values were assessed through an independent sample Mann Whitney U Test. All other baseline group means were compared using independent t-tests to determine whether there were initial group differences. Multilevel modelling (MLM) was used to determine if there were differences between groups over time for any outcomes. These models included the following fixed effects: age (continuous), group (binary), sex (binary), number of sessions missed (continuous), time (categorical) and time by group interaction. Time is also included as a random effect for the intercept. Lean body mass and subcutaneous adipose tissue models failed to converge when including the number of sessions missed as a fixed effect, so number of sessions missed was removed from the model for these two outcomes. MLM allows for multiple observations to be nested within a participant (intra-person clustering), thus removing the need for observations to be independent of each other. There are two levels of effects within MLM. Level-1 effects are the individual, or "within-group effects" (as with ordinary least squares regression) that reflects how a predictor changes over time within an individual. Level-2 effects occur at the higher order, in this case group assignment, and are considered "between-group effects." Whereas repeated measures analyses assume that individuals experience the same trajectory of change over time and aggregate these individual responses for an overall group trajectory, MLM accounts for the fact that individuals start at different points (the equation's intercept) and change at different rates (the equation's slope) over time. The level-1 subcomponent of the model reflects how each participant changed over time, and the level-2 subcomponent reflects how these changes differed between participants [236]. Analyses were conducted hierarchically through the maximum likelihood method, and both fixed and random effects were explored. All analyses were conducted using IBM SPSS Statistics version 23.

Results

Baseline characteristics of participants are presented below (Table 2).

Independent t-tests showed no group differences for any baseline characteristics.

Table 2. Baseline participant anthropometric and strength characteristics by group

	Soy (n=30)		Whey (n=31)		Total (n=61)		
	M	***(SD)***	***M***	***(SD)***	***M***	***(SD)***	***P***
Height (cm)	166.93	(10.03)	168.20	(7.04)	167.57	(8.59)	0.57
Male/Female	9/21		10/21		19/42		0.85
Age	21.83	(4.27)	22.22	(3.38)	22.03	(3.81)	0.69
Ethnicity							
White (n/%)	21/70		18/58		39/64		0.69
Non-white (n/%)	9/30		13/42		22/36		
Weight (kg)	65.47	(12.23)	67.15	(9.65)	66.32	(10.93)	0.55
Lean body mass (kg)	42.33	(9.77)	43.63	(8.24)	42.99	(8.97)	0.48
Fat mass (kg)	19.41	(6.95)	20.07	(6.23)	19.74	(6.55)	0.70
Visceral adipose tissue (g)	292.14	(370.1)	252.88	(238.8)	271.54	(306.2)	0.81
Body fat percentage (%)	31.38	(8.54)	31.58	(8.00)	31.48	(8.20)	0.92
Body mass index	23.40	(3.02)	23.67	(2.71)	23.54	(2.85)	0.71
Bone mineral density (g/cm^2)	1.19	(0.16)	1.19	(0.15)	1.19	(0.15)	0.87
Vastus lateralis thickness (cm)	2.18	(0.32)	2.30	(0.54)	2.24	(0.44)	0.29
Vastus intermedius (cm)	1.55	(0.38)	1.58	(0.44)	1.57	(0.41)	0.84
Combined muscle thickness (cm)	3.85	(0.60)	4.00	(0.89)	3.93	(0.76)	0.45

Subcutaneous adipose tissue thickness (cm)	0.93	(0.45)	1.06	(0.60)	1.00	(0.53)	0.35
Thigh circumference (cm)	52.81	(4.40)	53.62	(5.22)	53.23	(4.82)	0.52
Peak torque doing leg extensions at 60 degrees per second (Nm)	128.71	(47.11)	126.47	(43.96)	127.54	(45.12)	0.65
Peak torque doing leg flexions at 60 degrees per second (Nm)	62.08	(17.08)	61.69	(18.99)	61.88	(17.95)	0.58

Notes. *P* values represent between-group differences at baseline.

Of the 30 participants beginning training in the soy group and 31 in the whey group, four dropped out from each group between the baseline lab visit and the six-week visit. An additional four participants dropped out of the soy group and one from the whey group between the six-week and 12-week visits (see Figure 1). Independent t-tests show that were no significant baseline differences for any outcome measured between those who dropped out of the study at any time point and those who completed the 12-week intervention.

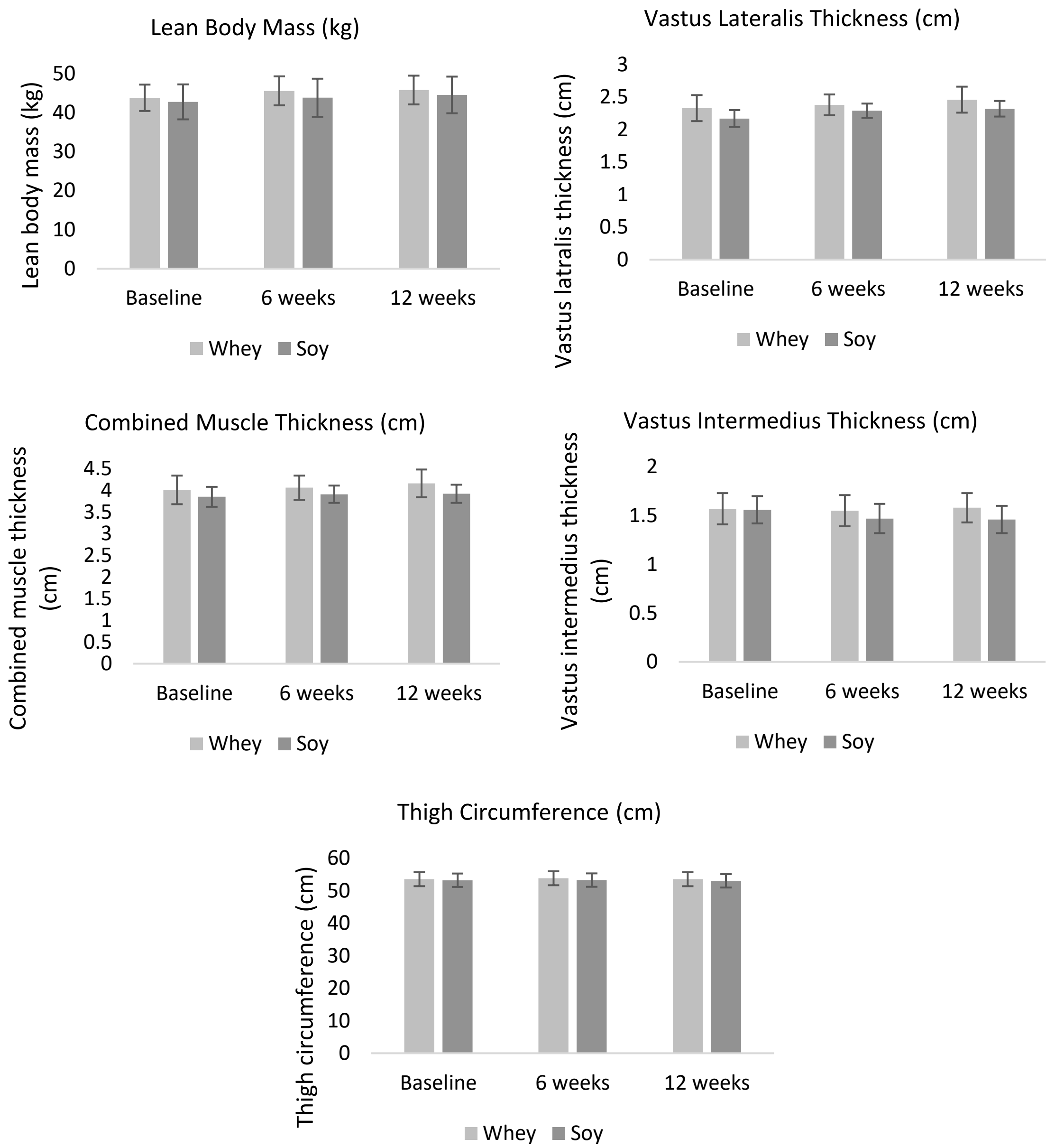
Multilevel modeling revealed that both groups significantly increased total body mass, BMI, lean body mass, and peak torque when doing leg extensions and flexions at 60 d/s with no significant differences between groups for change over time (see Tables 3-6 and Figures 2-5). Both groups also significantly decreased total fat mass, body fat percent, and subcutaneous adipose tissue thickness with no significant differences in change between groups over time (see Table 5 and Figure 4). There were trends for bone mineral density ($p=0.096$), vastus lateralis thickness ($p=0.077$), and combined muscle thickness (p=0.157) to increase by week 12 from baseline with no significant differences between groups over time; however, these trends did not reach statistical significance. Estimated mass of visceral adipose tissue, thigh circumference, and vastus intermedius thickness did not significantly change from baseline for either group. Data shown in Tables 3-6 reflect multi-level modeling with all participants who started the training (N=31 whey, 30 soy). Figure 7 shows individual changes in lean body mass at each time.

Table 3. Fixed effect estimates of between-group differences (soy vs. whey) at weeks 6 and 12, relative to baseline, for muscle assessments.

				95% CI	
	Beta	SE	p	lower	Upper
Lean body mass					
Week 6	0.001	0.004	0.866	-0.008	0.009
Week 12	-0.004	0.004	0.374	-0.013	0.005
Vastus lateralis thickness (cm)					
Week 6	-0.068	0.105	0.519	-0.141	0.278
Week 12	0.023	0.105	0.825	-0.186	0.232
Vastus intermedius thickness (cm)					
Week 6	-0.071	0.081	0.385	-0.231	0.090
Week 12	-0.105	0.081	0.197	-0.265	0.055
Combined muscle thickness (cm)					
Week 6	-0.006	0.157	0.972	-0.306	0.317
Week 12	-0.077	0.156	0.625	-0.388	0.234
Thigh circumference (cm)					
Week 6	-0.245	0.334	0.466	-0.912	0.421
Week 12	-0.178	0.390	0.650	-0.958	0.601

Notes. SE = standard error; CI = confidence interval; lean body mass data have been log10 transformed to achieve normality. All models are adjusted for age, sex, and number of training sessions missed. Training sessions missed has been removed from the lean body mass model as it failed to converge.

Figure 2. Muscle growth assessments by study group at baseline, 6 and 12 weeks.



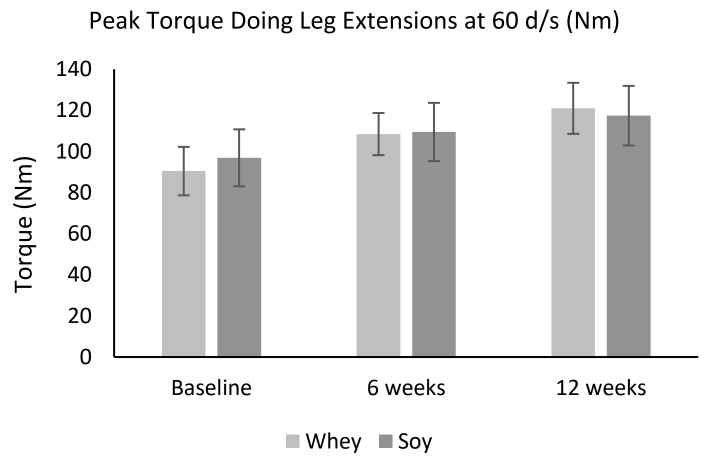
Data are model-based estimates. Error bars are 95% confidence intervals. All models are adjusted for age, sex, and number of training sessions missed. No significant time by group differences for any outcome. Lean body mass increased significantly from baseline at week 6 and 12.

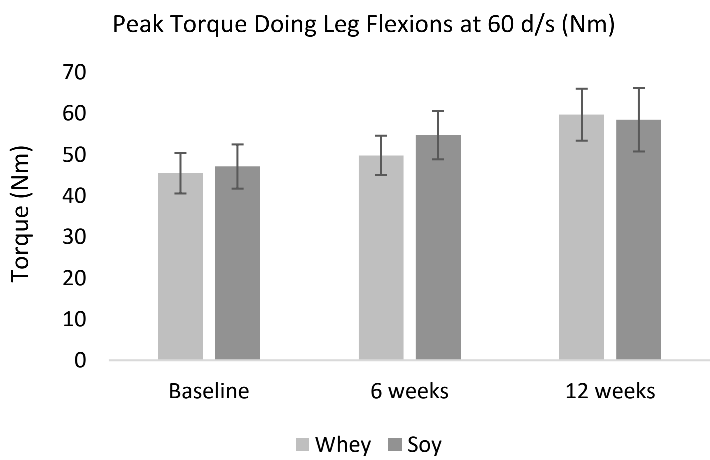
Table 4. Fixed effect estimates of between-group differences (soy vs. whey) at weeks 6 and 12, relative to baseline, for torque.

	Beta	SE	P	95% CI Lower	95% CI Upper
Torque Extensions					
Week 6	-0.035	0.072	0.630	-0.177	0.108
Week 12	0.032	0.073	0.663	-0.113	0.176
Torque Flexions					
Week 6	0.242	0.270	0.374	-0.295	0.778
Week 12	-0.261	0.277	0.348	-0.810	0.288

Notes. SE = standard error; CI = confidence interval. Torque extensions data have been log10 transformed to achieve normality; torque flexions data have been square root transformed to achieve normality. All models are adjusted for age, sex, and number of training sessions missed.

Figure 3. Torque at 60 d/s by study group at baseline, 6 and 12 weeks.





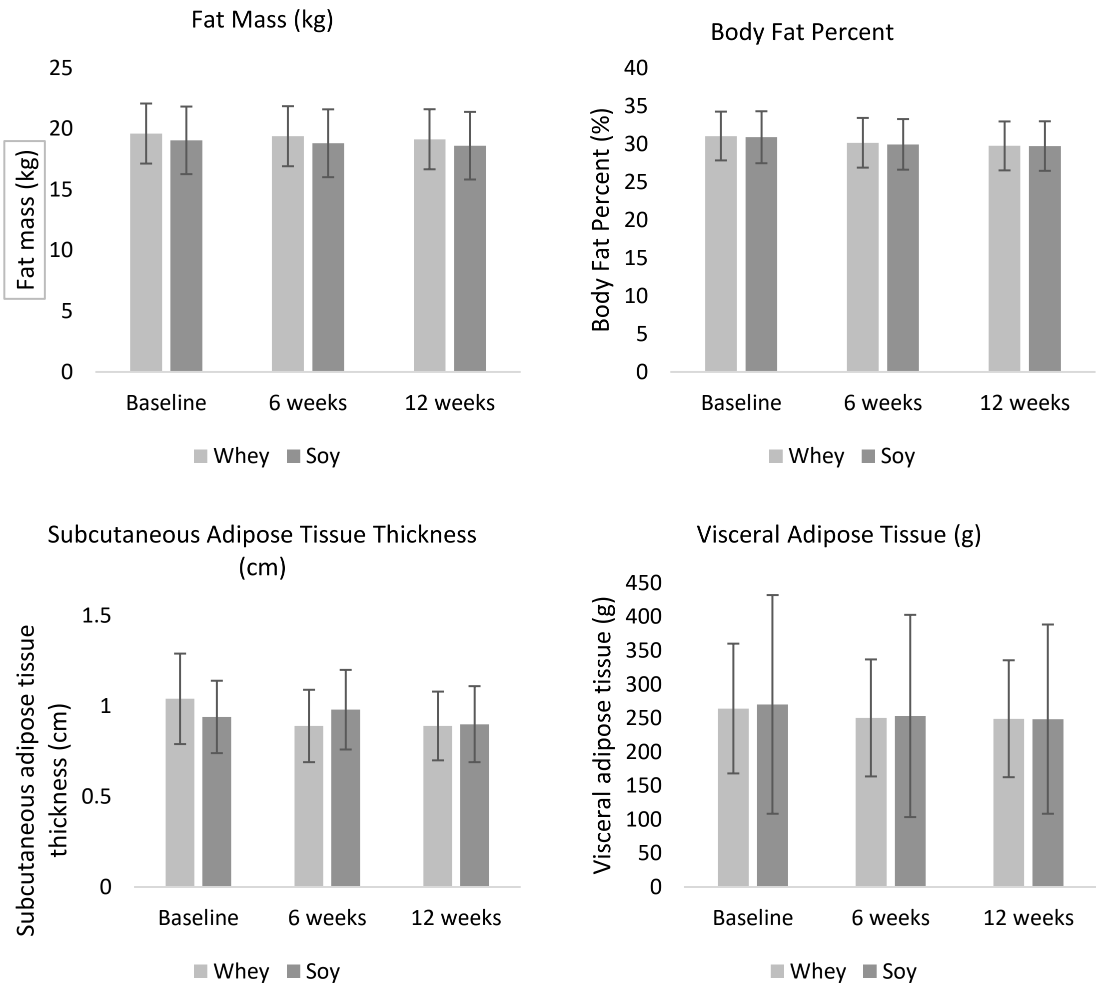
Data are model-based estimates. Error bars are 95% confidence intervals. All models are adjusted for age, sex, and number of training sessions missed. No significant time by group differences for any outcome. Torque increased significantly from baseline at weeks 6 and 12 for extensions and flexions.

Table 5. Fixed effect estimates of between-group differences (soy vs. whey) at weeks 6 and 12, relative to baseline, for adiposity.

				95% CI	
	Beta	SE	P	lower	Upper
Fat mass					
Week 6	-0.019	0.281	0.946	-0.577	0.539
Week 12	0.040	0.286	0.890	-0.529	0.608
Body fat percent					
Week 6	-0.048	0.378	0.900	-0.799	0.703
Week 12	0.139	0.385	0.718	-0.625	0.904
Visceral adipose tissue					
Week 6	-3.223	23.020	0.889	-48.939	42.494
Week 12	-6.709	23.448	0.775	-53.275	39.856
Subcutaneous adipose tissue					
Week 6	0.168	0.079	0.035	0.012	0.324
Week 12	0.111	0.080	0.168	-0.048	0.270

Notes. SE = standard error; CI = confidence interval; visceral adipose tissue data have been log10 transformed to achieve normality. All models are adjusted for age, sex, and number of training sessions missed. Training sessions missed has been removed from the subcutaneous adipose tissue model as it failed to converge.

Figure 4. Adiposity by study group at baseline, 6 and 12 weeks.



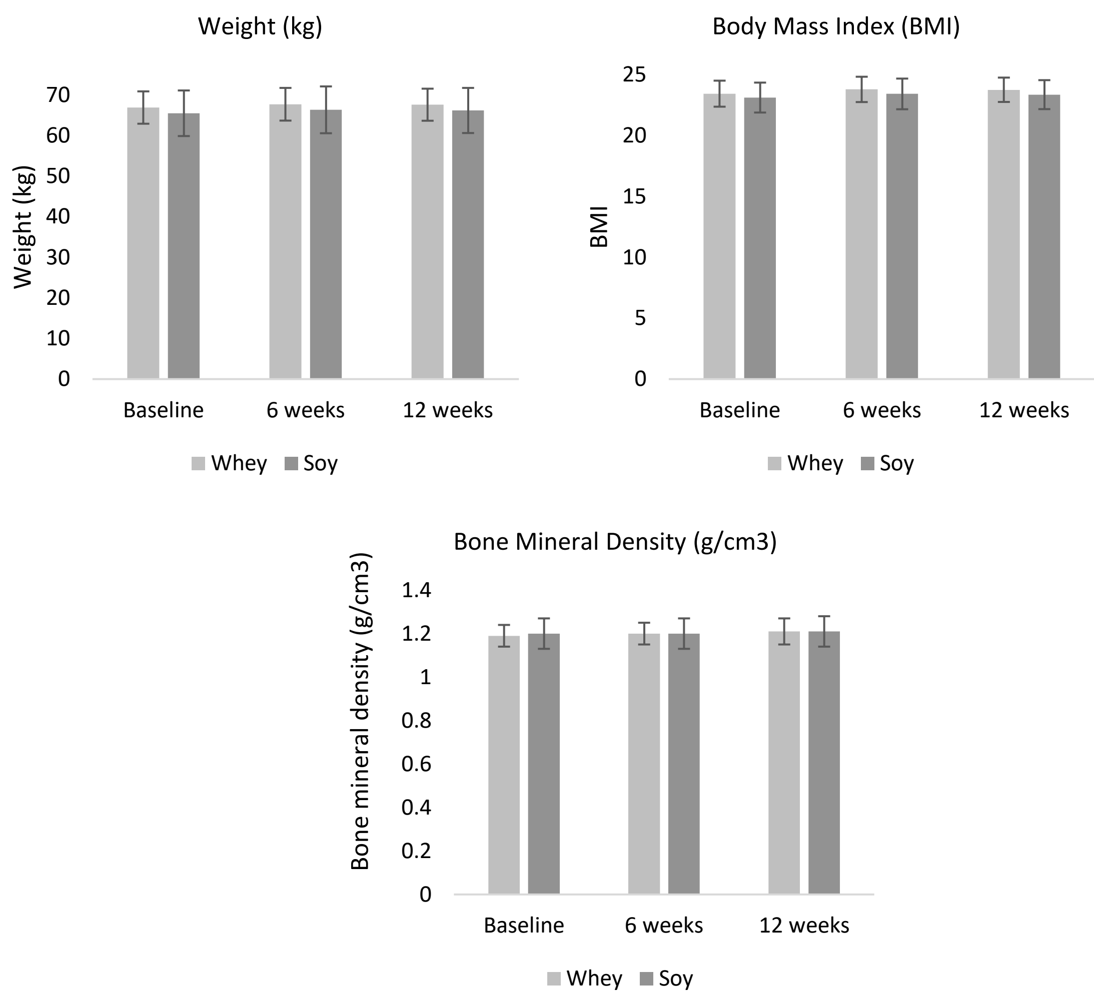
Data are model-based estimates. Error bars are 95% confidence intervals. All models are adjusted for age, sex, and number of training sessions missed. No significant time by group differences for any outcome. Body fat percent and subcutaneous adipose tissue significantly decreased from baseline at weeks 6 and 12, and fat mass decreased significantly from baseline at week 12.

Table 6. Fixed effect estimates of between-group differences (soy vs. whey) at weeks 6 and 12, relative to baseline, for weight, body mass index, and bone mineral density.

				95% CI	
	Beta	SE	P	Lower	Upper
Weight					
Week 6	0.038	0.455	0.934	-0.865	0.941
Week 12	-0.004	0.463	0.994	-0.923	0.916
Body mass index					
Week 6	-0.064	0.161	0.693	-0.384	0.25
Week 12	-0.092	0.164	0.578	-0.418	0.235
Bone mineral density					
Week 6	-0.004	0.004	0.407	-0.012	0.005
Week 12	-0.003	0.004	0.523	-0.012	0.006

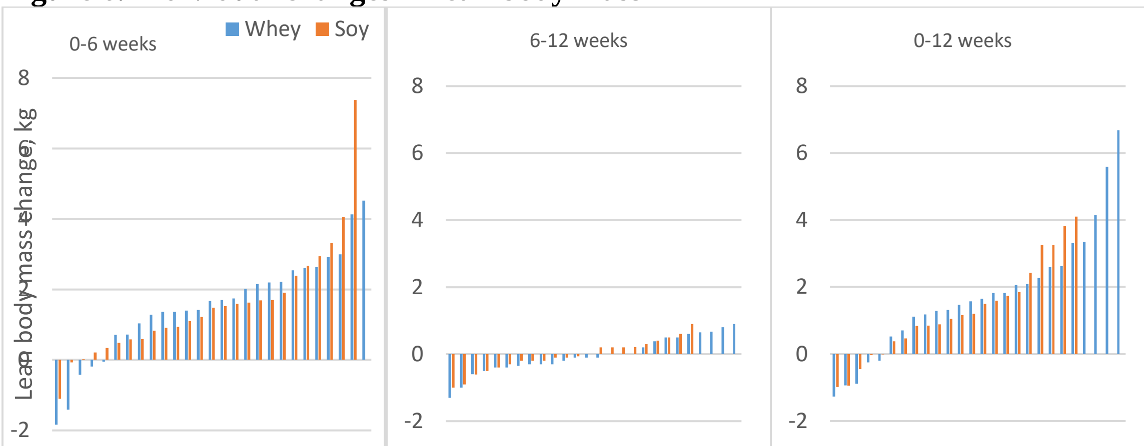
Notes. SE = standard error; CI = confidence interval; visceral adipose tissue data have been log10 transformed to achieve normality. All models are adjusted for age, sex, and number of training sessions missed.

Figure 5. Weight, body mass index, and bone mineral density by study group at baseline, 6 and 12 weeks.



Data are model-based estimates. Error bars are 95% confidence intervals. All models are adjusted for age, sex, and number of training sessions missed. No significant time by group differences for any outcome. Weight and body mass index increased significantly from baseline at weeks 6 and 12.

Figure 6. Individual changes in lean body mass



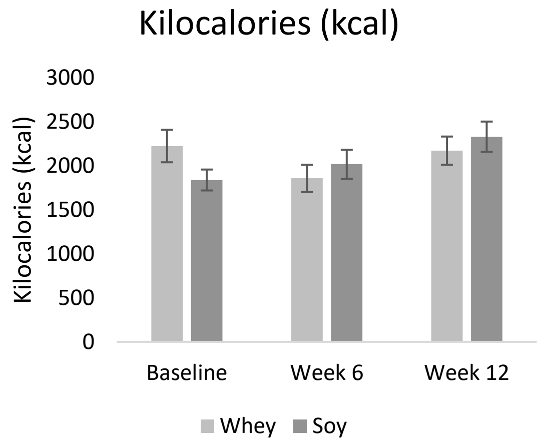
Nutrient intake data were based upon three-day food logs that were completed for two weekdays and one weekend day corresponding to each laboratory visit (see Table 7 and Figures 7-10). Dietary data displayed in Table 7 did not include the daily protein supplement for the study. Total protein and amino acid profile of the supplements are displayed in Table 1. Multilevel modeling indicated no differences in caloric intake, total grams of carbohydrate or protein, or percent contribution of carbohydrate or protein to caloric intake by group over time. However, there was a significant time by group difference for total fat intake and a trend for percent contribution of fat to the diet with participants in the soy group reporting consuming more dietary fat. Both groups consumed nutrients within the Acceptable Macronutrient Distribution Range (AMDR) for protein and carbohydrate (45-65% carbohydrate, 20-35% fat, 10-35% protein), although carbohydrate intake was at the low end of the recommended range [157]. Participants in the whey group had mean intakes of fat as a percent of their caloric consumption within the AMDR, but participants in the soy group slightly exceeded this recommended intake at weeks 6 and 12. When using independent t-test to compare baseline nutrient intake between completers (n=31) and non-completers (n=5), there were significant differences for kilocalories (p=.039), grams of fat (p<.000) and grams of carbohydrate (p=.041) with non-completers consuming less of each nutrient. Baseline grams of protein consumed and macronutrient distribution did not differ between completers and non-completers.

Table 7. Fixed effect estimates of between-group differences (soy vs. whey) at weeks 6 and 12, relative to baseline, for nutrient intake

				95% CI	
	Beta	SE	P	Lower	Upper
Kcal					
Week 6	546.678	292.710	0.067	-39.980	1133.335
Week 12	544.925	301.582	0.076	-59.619	1149.469
CHO (g)					
Week 6	55.214	35.895	0.130	-16.913	127.340
Week 12	45.139	36.956	0.228	-29.143	119.421
CHO (% kcal)					
Week 6	-1.657	3.091	0.594	-7.875	4.560
Week 12	-4.730	3.178	0.143	-11.124	1.664
PRO (g)					
Week 6	9.821	13.213	0.460	-16.650	36.293
Week 12	18.069	13.600	0.189	-9.182	45.320
PRO (% kcal)					
Week 6	-3.315	1.727	0.060	-6.781	0.150
Week 12	-0.695	1.776	0.697	-4.260	2.870
Fat (g)					
Week 6	31.822	14.415	0.031	2.934	60.709
Week 12	34.037	14.850	0.026	4.272	63.803
Fat (% kcal)					
Week 6	4.954	2.475	0.051	-0.019	9.928
Week 12	5.454	2.545	0.37	0.337	10.570

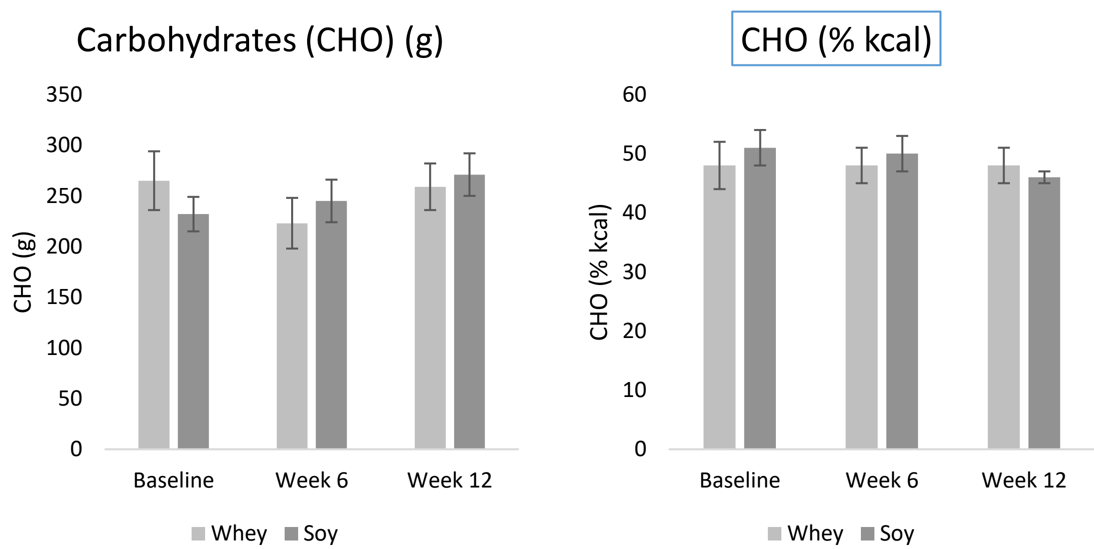
Notes. SE = standard error; CI = confidence interval. All models are adjusted for age, sex, and number of training sessions missed.

Figure 7. Kilocalorie consumption by study group at baseline, 6 and 12 weeks.



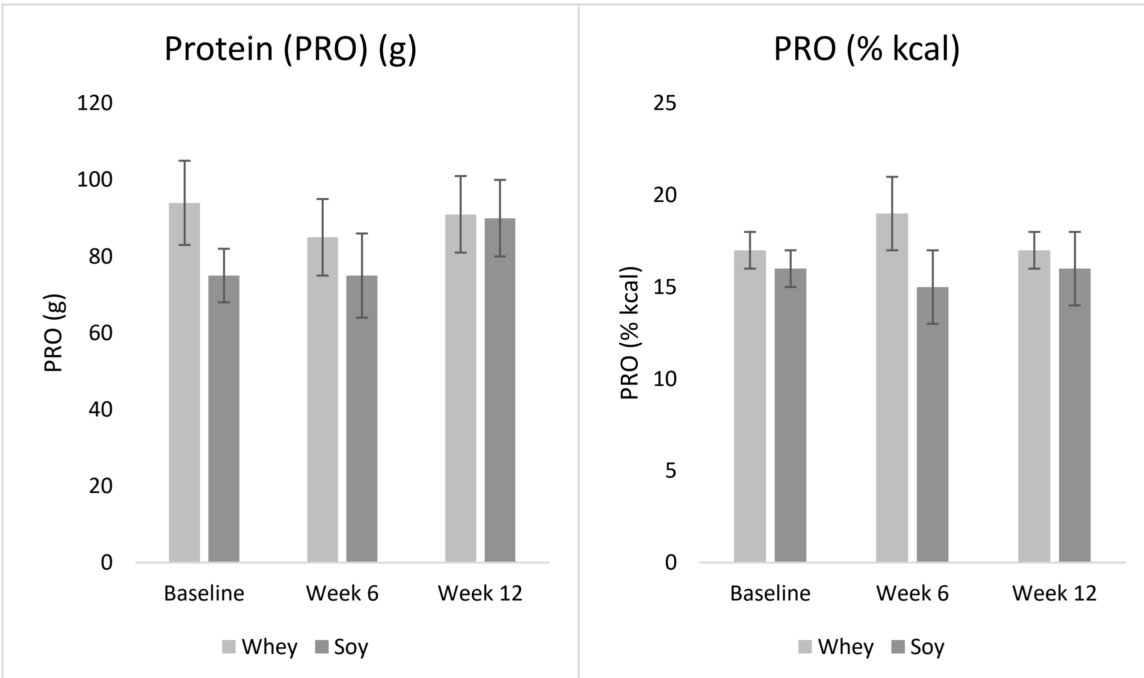
Data are model-based estimates. Error bars are 95% confidence intervals. All models are adjusted for age, sex, and number of training sessions missed. No significant time by group differences.

Figure 8. Carbohydrate consumption by study group at baseline, 6 and 12 weeks.



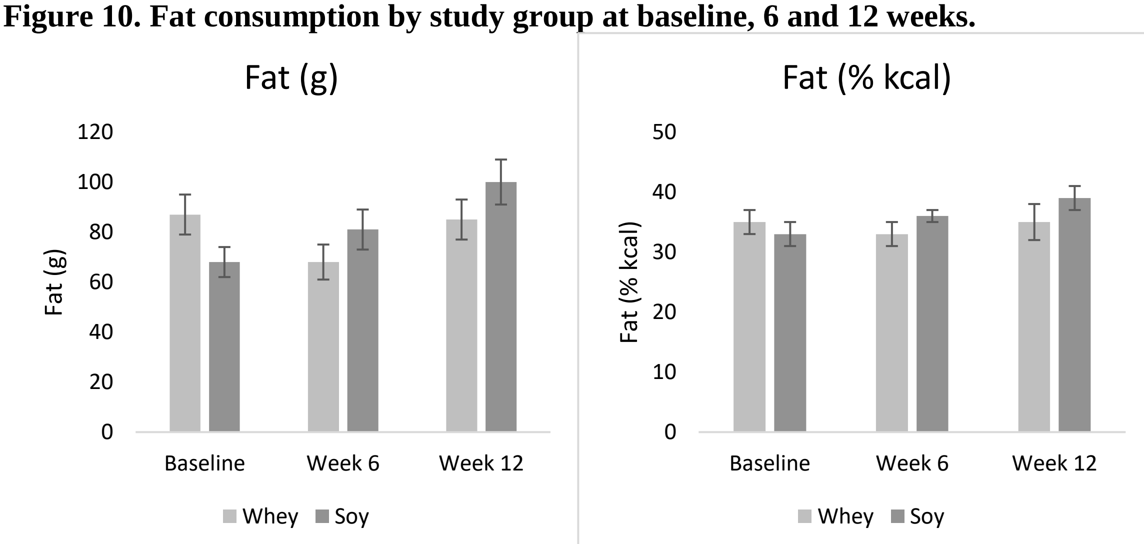
Data are model-based estimates. Error bars are 95% confidence intervals. All models are adjusted for age, sex, and number of training sessions missed. No significant time by group differences.

Figure 9. Protein consumption by study group at baseline, 6 and 12 weeks.



Data are model-based estimates. Error bars are 95% confidence intervals. All models are adjusted for age, sex, and number of training sessions missed. No significant time by group differences.

Figure 10. Fat consumption by study group at baseline, 6 and 12 weeks.



Data are model-based estimates. Error bars are 95% confidence intervals. All models are adjusted for age, sex, and number of training sessions missed. There were significant group differences for fat (g) at weeks 6 and 12, and for fat (%) at week 12.

Discussion

Although many chronic resistance exercise training and protein supplementation studies have been published to date, some discrepancy in results remains regarding efficacy of protein supplementation for augmenting lean body mass development beyond that experienced from resistance training alone or from supplementing with isocaloric carbohydrate [182, 237, 238], and advantages of protein supplementation are often marginal. This is intriguing given that protein or amino acid supplementation following an acute bout of exercise has been demonstrated to stimulate MPS to a greater extent than fasting conditions or carbohydrate feeding [239-241]. It appears that, relative to the acute effect of consumption of protein following resistance exercise, there is a reduced effect for protein supplementation in conjunction with resistance training to stimulate muscle growth long-term [238]. Furthermore, results from long-term training studies are mixed regarding whether a certain type of protein (such as whey, soy, or protein blends) may be superior for supporting lean body mass development [50-54, 181, 186, 242]. Likely possible causes for differences observed between studies could relate to the differing amounts of protein provided across studies as well as the possibility that differences between protein sources are attenuated at intakes above amounts containing two grams of leucine [238].

To test this hypothesis, we matched our protein supplements for leucine content (two grams) instead of total protein and found no group effect for total lean body mass development based on DXA results or regional muscle growth based on ultrasonography. Although the soy group received 28 additional kcal from consuming seven more grams of protein daily, it is unlikely that this difference could have contributed to potential changes in anabolic response between groups [238, 243]. These results are consistent with studies in which participants have been provided with protein in amounts containing more than two grams of leucine, regardless of protein source [50-52].

Since the present study did not have an isocaloric maltodextrin placebo or training group not receiving any supplement, we cannot conclusively say that either the soy or the whey group increased lean body mass significantly more than what would be expected from training alone, or from training supplemented with carbohydrate. However, multiple studies have demonstrated greater increases in lean body mass from resistance training and supplementing with protein relative to carbohydrate [51, 54, 242, 244, 245]. Other studies, however, have found no significant differences between certain types of protein and carbohydrate in terms of lean body mass changes [53, 54, 186], suggesting that the training, in conjunction with added calories (regardless of source), is driving the anabolic effect.

Another factor that may affect responsiveness to protein supplementation with training is the amount of protein habitually consumed in the diet. Participants in the present study were well-nourished, consuming ~1.3 grams of protein per kilogram of body weight (g/kg). Other work has suggested that among persons routinely consuming protein at levels meeting or exceeding the RDA, there are likely to be negligible further increases in lean body mass beyond that due to training alone [237]. However, protein intake well above the RDA of 0.8 g/kg, not including any supplement, is commonly reported for participants in training and supplementation studies [51, 53, 54, 181, 186, 242, 245, 246]. Some of these studies still demonstrate differences between type of protein supplement [53, 54, 246] or between protein and carbohydrate [51, 242, 245] for changes in lean body mass. Future studies would benefit from including a placebo group that does not receive any supplement to demonstrate what changes are due simply to training alone to help establish what further benefit supplements (carbohydrate or protein) provide.

Not only were there no overall differences between groups for increases in LBM, there was also no time by group difference at week 6, indicating that both groups were increasing LBM at comparable rates over time. Interestingly, the majority of the changes in lean body mass based on DXA data occurred during the first six weeks of training (see Figure 6). However, the increase in the thickness of the vastus lateralis muscle based on ultrasonography increased at a steady rate over the 12 weeks (see Figure 2). The apparent more rapid increase in LBM for the first six weeks of the study may reflect physiological changes in addition to muscle growth that resulted from training, such as increased muscle glycogen storage [247], and its associated water storage, which would impact total body water [248], and consequently lean body mass readings through a DXA scan. Although the change in vastus lateralis thickness did not quite reach significance ($p=0.77$), the amount of change observed in the present study was close to, but slightly less than, that reported in other studies at a similar location [186, 249-251]. Since not all studies measure muscle thickness at exactly the same site and do not use the same training program, it would be expected for there to be some variability in muscle thickness changes reported.

In addition to increases in lean body mass, we also observed significant decreases for total fat mass, body fat percent, and subcutaneous adipose tissue thickness, although visceral adipose tissue did not change significantly ($p=0.342$). Participants were clearly instructed not to change their physical activity level, apart from the addition of resistance training, or to change their diet, apart from consuming the dietary supplement. A reduction in percent body fat would be expected from the addition of lean body mass due to training, but the reduction in total fat mass and subcutaneous adipose tissue is noteworthy. Our results are consistent with those reported in a meta-analysis by Cermak et al. which demonstrated a very modest favorable effect for protein supplementation versus placebo in terms of fat mass reduction with resistance training [182]. That VAT did not significantly decrease when subcutaneous adipose fat decreased is a bit surprising since typically percent decrease in VAT is greater than in subcutaneous adipose tissue [252]. The large standard deviations around the group means for VAT may contribute to this lack of significant change.

Although the literature presents mixed results regarding anabolic responses to supplementing with various types of protein or protein blends and carbohydrate, most studies, even those demonstrating different LBM responses, have shown no group differences for strength development [50, 51, 53, 54, 181, 186, 242]. Our results are consistent with this since both groups significantly increased their peak torque when doing leg extensions and flexions at 60 d/s to a similar extent. Although muscle mass certainly contributes to strength, these results attest to other possible factors impacting strength development, particularly among novice weight-lifters, in the early stages of training, such as neuromuscular adaptation [253, 254].

The present study is unique and presents valuable contributions to the literature in several ways. Although in previous studies leucine content of supplements has been matched between whey protein and a soy-dairy blend to acutely assess muscle protein fractional synthetic rate following resistance exercise [60] and lean body mass development following a resistance training study [186], to the authors' knowledge, this is the first training study to match a 100% plant protein supplement to an animal protein supplement for leucine content.

Another novel aspect of this study was in measuring changes in strength and body composition during the intervention in addition to baseline and post-intervention. While there are data indicating that non-responders, or compensators, may be identified in studies examining fat loss rates after four weeks [255], similar patterns of responsiveness have been less-well explored with respect to lean body mass accrual and strength development resulting from resistance training programs. A notable exception was a nine month-long study by Volek, which included measurements at three, six, and nine months during the intervention. Results indicated that the majority of the changes in lean body mass and strength occurred after the first three months [54]. Our study explored this issue with data indicating responsiveness as early as six weeks. A 12-week resistance training study by Reidy and colleagues also demonstrated significant increases in LBM by week 6 [186].

Limitations As with any training and supplement study, important limitations existed. Although the research team emphasized that participants were to maintain their usual diet and physical activity levels apart from the study intervention, verification of adherence relied upon participant self-report with 3-day food logs administered at baseline, mid-intervention, and post-intervention. Similarly, no objective method of assessing physical activity outside of the training sessions, such as a pedometer or accelerometer, was employed in this study.

Another potential limitation of the study was the lack of an objective means of assessing compliance in consuming protein powder, such as a urinary assessment. We relied upon constant reminders from trainers and emails from researchers to ensure participant compliance.

Finally, there remain unanswered questions from this work in relation to other types of plant protein intake. Future research ought to include examination of whether similar responses are achievable utilizing other plant protein sources, or other sustainable protein sources, such as insect powder. As this was a supplementation study, future studies could expand on the literature with comparisons of responsiveness of vegetarians and omnivores to a training protocol employing whole-food diets based on either plant or animal protein sources. Additionally, future studies ought to include examination other methods to continue to stimulate increases in lean body mass beyond the initial weeks, either through changing the training stimulus more dramatically, further increasing caloric intake, or a combination thereof.

Since our study included both males and females, results are generalizable to both sexes. However, since our population was exclusively young, healthy non-vegetarian adults, the same pattern and magnitude of response may not be observed in an older population or a vegetarian one. As all of our participants were untrained, results also may not necessarily be generalizable to trained athletes.

Conclusions

The current study showed that supplementing with soy or whey protein, in amounts containing two grams of leucine, led to similar increases in lean body mass and strength development. Furthermore, assessing muscle growth through ultrasonography also indicated no significant differences between groups over time. Future work ought to examine this further by testing various other types of plant protein compared to animal protein and in other populations, such as the trained and the elderly, to determine if responses are similar.

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CHAPTER 6

CONCLUSION

The state of the science across multiple areas of research suggests clear and consistent environmental benefits of production of plants compared to producing meat and animal products for human consumption [2-6]. These benefits relate to land use, water use and quality, energy efficiency, and resource utilization (such as phosphate use), as well as reduced aggregate emissions of greenhouse gases [7, 12, 14, 256-258]. Even so, consumer awareness of the environmental impact of personal dietary choices remains remarkably low [8]. More specifically, the interest and population-specific application of plant-based diets is an area of research only just beginning to take shape [257, 259-261]. As such, it provides an important avenue for future work to investigate Americans' awareness of climate impacts of dietary choices, openness to incorporating more plant-based meals into their lives, and best practices for facilitating and maintaining such lifestyle changes.

Further, certain special populations, such as athletes, may have reservations about adherence to plant-based diets if they question the ability of such diets to adequately fuel their training, recovery, and performance. Understanding implications of consuming plant-protein and plant-based diets on athletic performance is paramount if athletes are to seriously consider adopting more sustainable dietary choices. As athletes competing in events that emphasize strength and power have somewhat different fueling needs compared to endurance athletes [150], it is important to understand how plant-based diets may impact performance in different ways. Multiple joint-position stands by groups such as the Academy of Nutrition and Dietetics, the American College of Sports Medicine, and Dietitians of Canada have reported on the adequacy of well-planned vegetarian diets for athletes [150, 223], and the few studies thus far available have shown no performance differences between vegetarians and omnivores based on maximal strength, power, aerobic performance (maximal oxygen uptake) or anaerobic power and capacity (repeated sprint performance or Wingate test performance) [48, 49]. Likewise, our research showed no differences between long-term vegetarian and omnivore endurance athletes for peak torque doing leg extensions on an isokinetic dynamometer. However, our vegetarian athletes had higher maximal oxygen uptake, when expressed relative to body weight (ml/kg/min). As a number of the studies referenced in a review by Craddock were not actually with participants who adhere to a vegetarian diet outside of the study, our findings provide even more definitive support for the adequacy of vegetarian diets among endurance athletes. Furthermore, our work has demonstrated the sufficiency of a 100% plant protein supplement compared to an animal-based protein supplement in supporting comparable lean body mass and strength increases, in conjunction with resistance training, among untrained young men and women. However, larger and more rigorous, sport-specific studies ought to be conducted to examine any impacts of adoption of a vegetarian or vegan diet on athletic performance. At least one such study is presently underway with runners and can serve as an example upon which to base studies about athletes in other sports [177]. Also, as our resistance training intervention was conducted with untrained, healthy young men and women, future work ought to examine if such responses are consistent with highly trained athletes. Such studies with athletes will require trust to be built between coaches and researchers, and such research might need to take place in the off-season to alleviate any concern about dietary changes potentially adversely impacting performance. Larger studies of long-term vegan and vegetarian athletes, as well as long-term prospective studies following athletes who adopt vegetarian or vegan diets, will help answer questions about adequacy of long-term adherence to such diets for athletes in terms of performance. Finally, when considering optimal diets for performance, it is also important to remember that the health of athletes long beyond their competitive athletic career is of utmost importance, and as such incorporating assessments of key biomarkers when adopting vegetarian or vegan diets may be worthwhile, as well as training athletes about how to make sustainable dietary choices after they retire from competitive athletics.

Continuing education for sports dietitians regarding plant-based diets and impact on performance should be encouraged to help them provide the most current evidence-based recommendations to their athletes. Close communication of this current research should also be relayed to coaches, athletic trainers, and strength and conditioning specialists as many athletes get nutrition advice from them, and collegiate coaches scored particularly low in nutrition knowledge in a survey of coaches across the country at Division I, II, and III schools [262]. Poor nutrition understanding by coaches, and consequent non-ideal dietary advice for their athletes, has been documented internationally as well [263].

Although strength, power, and body composition are important in many sporting contexts, understanding how to optimize strength and lean body mass development is not just a matter of concern for athletes or body builders. Sarcopenia, or the progressive loss of muscle mass with aging, is a serious public health concern and directly affects quality of life, mortality, and ability to live independently [264]. Since older persons require more protein to elicit comparable muscle protein synthesis relative to younger individuals [168, 189, 265, 266], studies of plant-based protein or protein blends should be conducted both with healthy young populations as well as older ones. Our work has demonstrated that consuming a 100% soy protein supplement matched for leucine content compared to a whey protein supplement, in conjunction with strength training, resulted in no significant differences for lean body mass development or strength among healthy, young people. This has not been tested yet in more vulnerable populations such as the malnourished, those suffering from cachexia, and the elderly, and their responsiveness to various types of plant-based protein remains to be ascertained. As our work and much of the existing literature comparing plant and animal protein's effect on anabolism and strength development has compared soy protein with a type of dairy protein (ex: whey, casein, or whole milk), future research ought to examine other types of plant protein or other sustainable high-quality protein, such as insect protein powder, for consumer acceptability and physiological efficacy [145, 267, 268]. Developing various ratios of protein blends to optimally promote muscle protein synthesis, while minimizing environmental impact, is another area necessitating future research. It has already been demonstrated that a soy-dairy blend effectively supports lean body mass development as well as (and perhaps better than) whey protein, but this particular blend was 75% dairy and only 25% soy [186, 188]. It is possible that people who may be opposed to switching from their habitual whey protein supplement may be open to switching to a protein blend emphasizing plant protein with a smaller contribution from animal protein.

Plant-based diets can play an important role in addressing health, environmental impact, and even sport performance simultaneously. Further, food systems built to promote the adoption of more plant-based diets can provide greater support to small-scale, locally focused farm operations that deliver value in terms of healthy food and community vitality to the communities in which they operate. In spite of this, most people are unaware that their dietary choices have profound environmental consequences; therefore, informing athletes and the American public as a whole about the connection between human nutrition and environmental health is needed. Integrated approaches highlighting the interrelatedness of physical and environmental health may be an effective way to promote adherence to such lifestyle changes. Voluntary simplifiers, for example, are people who willingly choose to live below their means in order to reduce materialistic influence in their lives [269]. Part of this lifestyle approach frequently involves increased physical activity through active transportation (such as walking and bicycling), community involvement through shopping locally at farmers' markets, reducing consumption of meat, and eating locally raised meat for those who continue to include it in their diets [270]. Although such a lifestyle is not specifically focused on trying to improve human or environmental health, many of these choices do promote physical and environmental well-being. For example, purchasing locally grown food through a community supported agriculture (CSA) program, farmers' market, or food hub may promote consumption of fruit and vegetables, particularly when venues accept forms of payment such as SNAP and WIC benefits [271, 272]. Furthermore, buying locally helps bolster the local economy [30, 79]. Additionally, this may provide a sense of place and connection with where one lives, and foster relationships between growers and consumers [9, 97].

Consumer interest in local foods is increasing [21], but farming, particularly on a small-scale, remains a challenging lifestyle. Small, local farms comprise the majority of farms in America, yet operating such enterprises is an extremely demanding and often low-paying profession, one that typically needs to be supplemented with income from another job. Since the majority of principal operators of farms are nearing retirement age [23], it is critical that a new generation of farmers can be sufficiently motivated to enter into this profession in order to continue having produce available to residents of all economic levels locally. Our work has demonstrated that these patterns are consistent in Arizona and New Mexico, and that farmers in the southwest face some unique obstacles related to farming in the arid desert that are not reported elsewhere in the literature. Future work ought to develop strategic interventions at all levels (from federal government through local community involvement) to promoting programs that will increase consumer consumption of fruits and vegetables, especially from local producers. As consumers see the environmental benefit of increasing consumption of plant foods, the economic impact on their regional economy of buying at least some food locally, and health benefits of consuming more fruits and vegetables, this will likely drive continued participation in such patterns. With respect to athletes, including sustainably produced local foods on athletes' training tables and educating them about procurement of healthy plant-based foods at home and on the road for competition may be the way of the future to ensure physical and environmental health. Dualistic mentalities separating health and athletic performance from environmental considerations cannot be an option any longer;

rather, systems-oriented thinking and action can better ensure that we continue to have vibrant food systems that can support the dietary needs of our growing population.

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APPENDIX A

STATEMENT OF CO-AUTHOR AGREEMENT

Both co-authors of the article "Cardiorespiratory fitness and peak torque differences between vegetarian and omnivore endurance athletes: a cross-sectional study" are on my dissertation committee and have provided their agreement to including this article as a chapter in my dissertation.

APPENDIX B

LIST OF ABBREVIATIONS

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AMDR: Acceptable Macronutrient Distribution Range

BCAA: Branched Chain Amino Acid

DIAAS: Digestible Indispensable Amino Acid Score

DXA: Dual X-ray Absorptiometry

EAA: Essential Amino Acid

FAO: Food and Agriculture Organization

FDA: Food and Drug Administration

LBM: Lean Body Mass

LOV: Lacto-Ovo Vegetarian

MPS: Muscle Protein Synthesis

PDCAAS: Protein Digestibility Corrected Amino Acid Score

RDA: Recommended Dietary Allowance

USDA: United States Department of Agriculture

VAT: Visceral Adipose Tissue

WHO: World Health Organization