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Sustainability Dimensions of a North American Lentil System in a Changing World

Teresa Warne[1], *Selena Ahmed*[1*], *Carmen Byker Shanks*[1] *and Perry Miller*[2]

[1] Montana State University Food and Health Lab, Department of Health and Human Development, Montana State University, Bozeman, MT, United States, [2] Cropping Systems Laboratory, Department of Land Resources and Environmental Science, Montana State University, Bozeman, MT, United States

Food production and consumption are among the largest drivers of global change. The adoption of lentil in production systems and in plant-based diets is a food system solution that can support the environmental, socio-economic, and human health dimensions of sustainability. The purpose of this study is to evaluate producer and consumer perceptions of the sustainability profile of the lentil system in Montana (USA), and the surrounding region that includes Idaho (USA), North Dakota (USA), Washington (USA), and Canada, in the context of global change. Surveys were conducted with lentil producers ($n = 63$; conventional $n = 42$, organic $n = 15$, and mixed management $n = 6$) and consumers ($n = 138$) in the rural state of Montana (USA). The most prevalent agronomic reason for including lentil in production systems reported by producers is to diversify crop rotation (92%). The most prevalent economic reasons for including lentil in rotation reported by producers is to capitalize on dryland production (95%) and to serve as a cash crop (87%). With respect to lentil consumption, the most prevalent health-related perceptions were that eating lentils helps to improve nutrition (88%), feel satiated or full (85%), and support a plant-based diet (81%). Consumers and non-consumers of lentils alike reported they would increase lentil consumption based on environmental (78%), economic (75%), and health and nutrition (72%) information contrasting lentils and animal-based protein sources. Overall, findings highlight how the lentil system supports multiple dimensions of sustainability based on the perspectives of study informants. Additionally, findings elucidate barriers and opportunities for promoting lentil in agricultural systems and diets. Impacts of market, policy, and climate change on lentil production, and lack of consumer knowledge on benefits of lentils to help meet food security through a sustainable diet, challenge sustainability dimensions of lentil in the food system.

Keywords: lentil, sustainability, food security, management practices, consumption

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Tahira Fatima,
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***Correspondence:**
Selena Ahmed
selena.ahmed@montana.edu

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INTRODUCTION

One of the greatest societal challenges of our times is to feed a growing population a healthy and nutritious diet in an environmentally, economically, and socially sustainable way (Tilman and Clark, 2014; Willett et al., 2019). Food production and consumption are among the largest drivers of environmental degradation (Meybeck and Gitz, 2017) and global change (Willett et al., 2019) with dietary patterns impacting numerous facets of society (Mason and Lang, 2017; Meybeck and Gitz, 2017). The food system is further challenged by population growth, food insecurity, and food justice (Popkin et al., 2012; Tilman and Clark, 2014). The expected rise in global population from ∼7.5 billion people to 9.7 billion people by 2050 will place increased pressure on ecosystems and society to ensure food security for all (Zhang et al., 2007; United Nations Department of Economic and Social Affairs (UN DESA), 2019). These food system challenges are exacerbated by climate change with notable implications for sustainability (Mason and Lang, 2017; Willett et al., 2019).

In recognition of the aforementioned challenges, a sustainable food systems approach is increasingly recognized and promoted to support environmental and human wellbeing (Johnston et al., 2014; Herforth et al., 2017; Mason and Lang, 2017; Ahmed and Byker Shanks, 2019; Willett et al., 2019). A sustainable food systems approach seeks to enhance the environmental, socio-economic, and health aspects of sustainability from food production to consumption to waste, including processing, distributing, preparing, marketing, and accessing food involved (Herforth et al., 2017; Mason and Lang, 2017; Ahmed and Byker Shanks, 2019). For example, on the production side of food systems, producers can adopt agricultural practices including diversified crop rotations, cover crops, no-till, crop diversification, nutrient management, integrated pest management, and rotational grazing (Horrigan et al., 2002) to support ecosystem services including carbon sequestration, nutrient cycling, soil retention, increased water holding capacity, and soil fertility (Power, 2010). More specifically, including lentil in production diversifies crop rotation, provides nitrogen fixation, helps break pest and disease cycles, and is a dryland crop suitable to arid regions (Peoples et al., 2015). On the consumption side of food systems, consumers can change their dietary choices including adoption of plant-based diets rich in pulse crops (Gonzalez Fischer and Garnett, 2016; Herforth et al., 2017) and reduce food waste (Ahmed et al., 2018). More specifically, lentils are a pulse, and relatively affordable high-quality source of plant-based protein (∼24–26%), carbohydrate (∼60–64%), and dietary fiber (∼11–31%) (Ganesan and Xu, 2017).

There is a gap in research regarding barriers and opportunities that producers and consumers face with respect to lentil production and consumption using a sustainable food system approach, specifically in the context of North America. The following study addresses this research gap through the examination of the research question: *What are producer and consumer perceptions of the sustainability profile (environmental, socio-economic, and health dimensions) of the lentil system in Montana and surrounding region in the context of global change (climate change, land-use change, and market demand), and what are associated barriers and opportunities?* Findings may inform future research on lentil production and consumption, may inform policy in favor of supporting lentil production through producer incentives, and highlights education and outreach efforts on promoting lentils in plant-based diets to support sustainable food systems.

BACKGROUND

The food system experiences environmental, socio-economic, and health challenges which have an effect at a global though local scale. Food systems and global agricultural production are responsible for 19–29% of total greenhouse gas emissions (Vermeulen et al., 2012), account for 38% of land use (Foley et al., 2005), and 70% of freshwater use (Steffen et al., 2015). Livestock alone accounts for 14.5% of total greenhouse gas emissions (Gerber et al., 2013). Current dietary patterns across the globe, including the trend of increased consumption of animal-sourced foods in excess of dietary recommendations, burden ecosystems through pressures related to land use, resources used for feed production, and nutrient overload (Linseisen et al., 2002, 2009; Bouwman et al., 2013). In addition, roughly one-third of total food produced is lost or wasted along the food supply chain (Gustavsson et al., 2011; Fox and Fimeche, 2013; High Level Panel of Experts on Food Security and Nutrition (HLPE), 2014). Monetary estimates of global annual food loss are as high as USD 936 billion (Food Agriculture Organization of the United Nations, 2014). Finally, poor diets are a leading risk factor of the global burden of disease (Stanaway et al., 2018). More than 820 million people in the global food system are undernourished (Food Agriculture Organization of the United Nations, 2018) and more than 2 billion people are micronutrient deficient, despite global production of sufficient calories and nutrients to feed the world (Ritchie et al., 2018). At the same time, overweight and obesity afflict every country (Development Initiatives, 2018) and are associated with the rise in diet-related non-communicable diseases including coronary heart disease and cancer, risk of stroke, and type II diabetes (Aune et al., 2009; Popkin, 2009; Hu, 2011; Huang et al., 2012; Pan et al., 2012; Chen et al., 2013).

Transition from a modern Western diet to a plant-based diet has been found to have numerous benefits for environmental and human wellbeing including reductions in land use, greenhouse gas emissions, water use, and mortality risk and rates (Aleksandrowicz et al., 2016; Peters et al., 2016). Adoption of plant-based diets rich in pulse crops such as lentils, is a food system solution that is being promoted to support the environmental, socio-economic, and human health dimensions of sustainability including enhancing biodiversity, farmer livelihoods, food security, and nutrition while contributing to climate change mitigation and adaptation (Kissinger and Lexeme Consulting, 2016).

On the production side of food systems, growing lentil serves as a livelihood strategy for many populations in arid regions, such as the northern Great Plains, while providing a drought tolerant pulse crop that can be grown under relatively water-limited and rain-fed environments (Miller et al., 2002; Thornton and Cramer, 2012). Lentil and other pulse crops can reduce inorganic nitrogen fertilizer requirements, both during crop growth and for subsequent crops, in a crop rotation through their ability to fix nitrogen from the atmosphere by legume-rhizobia symbiosis in the soil (Lemke et al., 2007; Canfield et al., 2010; Burgess et al., 2012; Peoples et al., 2015). In addition, lentil may improve the productivity of the subsequent crop through increased availability of nitrogen (Burgess et al., 2012; Peoples et al., 2015). Lentil has a wide range of other production benefits including recycling of water and nutrients and helping with weed and pest control (Krupinsky et al., 2002; Lupwayi and Kennedy, 2007). The inclusion of lentil in production systems may increase soil-building capacity and stimulate nitrogen fixation, which could serve to create conducive conditions to reduced-tillage practices (Lafond et al., 1993; van Kessel and Hartley, 2000; Tanaka et al., 2010). These agricultural benefits may translate to environmental and economic savings with respect to use of nitrogen fertilizer (Burgess et al., 2012; MacWilliam et al., 2014) and pesticides (Krupinsky et al., 2002; Lupwayi and Kennedy, 2007). The integration of lentil in agricultural systems without tillage may also result in reduced labor and time as well as reduced use of machinery and fossil fuels (van Kessel and Hartley, 2000). Previous research has additionally highlighted some challenges due to the inclusion of lentil in rotation, that include harvesting challenges, increased soil erosion, and evaporative water loss due to sparse ground cover and short stubble height (Cutforth et al., 2002; Miller et al., 2002).

On the consumption side of food systems, lentils support food security as a dietary staple in many low to middle income countries such as India. The addition of lentils in diets are recognized for numerous health benefits. The nutritional profile of lentils include iron (∼6.5–7.7 mg), magnesium (∼47–69 mg), potassium (∼677–943 g), zinc (∼3.3–5.9 mg), and folate (∼479–555 μg) per 100 g raw lentils that may help support micronutrient deficiencies and healthy pregnancy (Mitchell et al., 2009; Sen Gupta et al., 2013; Ganesan and Xu, 2017; Singh, 2018; United States Department of Agriculture (USDA) Agricultural Research Service, 2018). In an *in vitro* experiment, extract of lentil showed a potential source of antioxidant phenolics that could be used in health promoting applications such as dietary supplements (Zou et al., 2011). Despite the potential health benefits of lentils, consumption of lentils and other pulse is relatively low in developed countries such as the United States of America (USA), where 7.9% of the population eat pulse on any given day (Mitchell et al., 2009). Due to socio-economic aspects, consumption of pulse is higher among lower income households and the Hispanic population (Lucier et al., 2000). In parallel with low pulse consumption in the USA, current dietary advice recommends ∼100–300 g pulse per week per each of the food groups "protein" and "vegetable," for a 2,000-kcal diet (United States Department of Health and Human Services and US Department of Agriculture, 2016).

As a relatively affordable and nutritious source of protein that can contribute to food security, lentil production has increased in the past few decades. In 2017, global lentil production and area harvested was ∼7.6 million tonnes and 6.6 million ha, respectively, compared to ∼2.8 million tonnes and 3.5 million ha in 1998 (Food and Agriculture Organization of the United Nations, 2017). With respect to lentil production, the top five lentil producing countries in 2017 included Canada (49%), India (16%), Turkey (6%), United States (4%), and Kazakhstan (4%) (Food and Agriculture Organization of the United Nations, 2017). The gap between lentil production in Canada and India has closed over the last 20 years (1998–2017), and since 2015 lentil production in Canada has surpassed production in India (Food and Agriculture Organization of the United Nations, 2017). Lentil production in Canada increased from around 480,000 tonnes (1998) to about 3.7 million tonnes (2017). While lentil production in the United States is much smaller compared to Canada, lentil production has steadily increased over the last 20 years from about 88,000 tonnes (1998) to about 340,000 tonnes (2017) (Food and Agriculture Organization of the United Nations, 2017).

Despite the increase in lentil production in the United States, as well as the recognized benefits of lentil for sustainability on both the production and consumption sides of the food system, there have been relatively few studies examining the contribution of lentil to sustainability and associated barriers and opportunities for lentil production and consumption. The aim of this study is to examine producer and consumer perceptions of the environmental, socio-economic, and health dimensions of sustainability of lentil production and consumption in Montana and greater region including Idaho (USA), North Dakota (USA), Washington (USA), and Canada. Due to status as the number one producer of lentil in the USA, Montana was selected as a study site (Montana Department of Agriculture, 2015). Lentil production in Montana has increased in the last 5 years from about 88,000 tonnes in 2013 to about 198,000 tonnes in 2017 [United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS), 2018; **Figure 1**].

Previous studies on lentil production in Montana and North America more broadly highlight the agronomic, environmental, and economic benefits of lentil. A study on the addition of lentil into spring wheat rotations to replace summer fallow in the semiarid Canadian prairies found that lentil improved overall productivity and sustainability while economic benefits were only realized when the price of lentil was above a certain threshold (Zentner et al., 2001). The inclusion of lentil and other pulse crops in an oil seed rotation system in western Canada was found to reduce environmental impacts of production and improve farm-level return (MacWilliam et al., 2014). A meta-analysis by Miller et al. (2002) on pulse and lentil management highlighted the climate resiliency of lentil based on the finding that weather parameters could not be related to lentil yield, thus allowing for the broad adaptation of lentil in the semi-arid region of the northern Great Plains (NGP). Similarly, a review by Cutforth et al. (2007) identified pulses and lentil as "plastic" and adaptable to various weather conditions in the semi-arid NGP region. Lentil was further found to have lower energy intensity and reduce the energy intensity of the subsequent crop in a Montana-based study (Burgess et al., 2012). Carlisle (2014) found resilience in diversified organic agricultural systems including lentil in the NGP was largely due to producer flexibility and willingness to adapt. Furthermore, with respect to nitrogen cycling, lentil, and other pulse included in rotation in sites in the NGP resulted in either no change or a small reduction in greenhouse gas emissions to the atmosphere (Lemke et al., 2007).

MATERIALS AND METHODS

Study Site

Surveys were carried out in the rural state of Montana (USA) and the greater lentil producing region of the northern Great

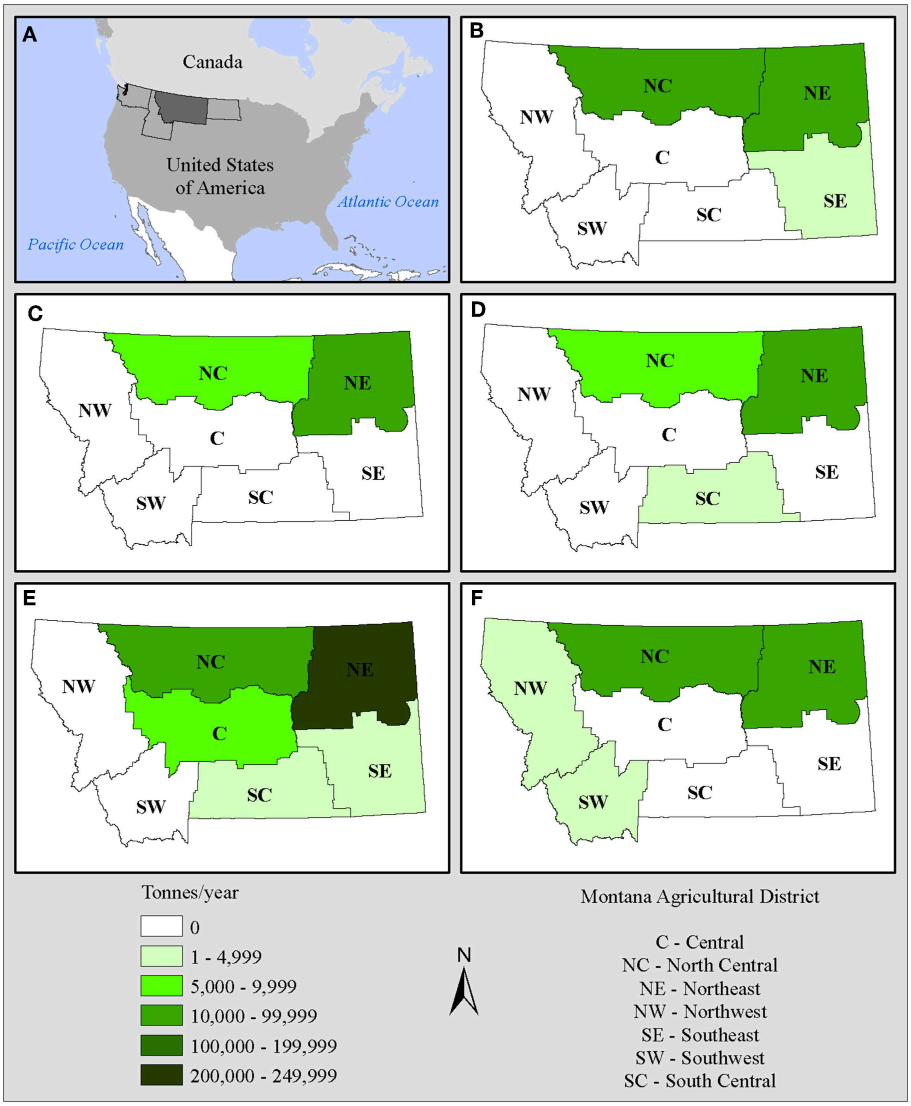

FIGURE 1 | Study region and change in montana lentil production. **(A)** Study region that includes Montana (USA), Idaho (USA), North Dakota (USA), Washington (USA), and Canada; and change in lentil production over time including **(B)** 2013 Montana lentil production (total tonnes per year) by agriculture district, **(C)** 2014 Montana lentil production (total tonnes per year) by agriculture district, **(D)** 2015 Montana lentil production (total tonnes per year) by agriculture district, **(E)** 2016 Montana lentil production (total tonnes per year) by agriculture district, **(F)** 2017 Montana lentil production (total tonnes per year) by agriculture district. Data source: Shapefiles from Montana State Library Geographic Information Clearinghouse and United States Geological Survey; lentil production from United States Department of Agriculture National Agricultural Statistics Service, accessed March, 2019.

Plains and the Pacific Northwest of North America. Montana is an expansive agricultural state with just under 27,000 farms operated on about 2.35 M ha. Ranch and rangeland accounts for about 81% of farm operated land area, with the remaining 19% of land dedicated to crop production (United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS), 2018). The region is suitable for numerous commodities including livestock and milk production, wheat and other cereal grains, oilseeds, pulse, hay and forage, surgarbeets, potatoes, and vegetables and fruits adapted to the semi-arid climate. Projections of climate change in Montana highlighted in the 2017 Montana Climate Assessment (Whitlock et al., 2017) include temperature increase between 2.5 and 3.3°C, increased overall precipitation with a decrease during summer months, longer growing season with an increase in frost-free days, and decreased mountain snowpack (Whitlock et al., 2017), all which point to hotter, drier, and longer summers.

Producer Structured Questionnaire

Lentil production sites and/or key informants were identified through local field experts working on dryland and sustainable agriculture in the region. Site visits to lentil production systems and stakeholders in Montana (Gallatin, Hill, and Missoula counties) were completed and key informants were interviewed ($n = 3$). A structured survey questionnaire was designed from feedback by key informants, and coupled with applicable material from review of the literature, to elucidate producer perceptions of the sustainability profile of the lentil system and associated barriers and opportunities (Thornton and Cramer, 2012; Villamil et al., 2012; Rejesus et al., 2013; Kissinger and Lexeme Consulting, 2016). The survey instrument was reviewed for face validity by content experts with expertise in agriculture, climate change, rural communities, sustainability, food systems, and sustainable diets. Revisions were made to the survey based on feedback from experts, and the survey was pilot-tested for validity with key informants at the Montana Pulse Day Conference (November 2018) to lentil producers ($n = 12$) from Montana (USA), and Idaho (USA), North Dakota (USA), Washington (USA), and Canada (herein "greater region").

The final survey instrument (**Supplementary Material**) included 33 multiple choice and open-ended questions divided into four sections: (1) Background of production system, (2) Management of lentil production, (3) Social, economic, and health dimensions of the lentil production system, and (4) Global change, challenges, and opportunities. Specifically, section One of the survey included general questions to understand background of the lentil production system including overall farm size, location, and management methods. Section Two of the survey included questions to understand current management practices, management outcomes and challenges, and on-farm environmental observations related to lentil production. Section Three of the survey included questions to understand perceptions of social, economic, and health dimensions of lentil production including questions specific to the North American consumer. Section Four of the survey included questions to understand challenges and future concerns and opportunities regarding lentil production in the context of global change including bioenergy production and feasibility.

Approval for human subjects to participate in this study was received from the Institutional Review Board (IRB) at Montana State University prior to survey implementation. Informed consent was obtained from all survey participants prior to completing the survey. The survey took ∼15–20 min to complete. The final survey instrument was input and formatted in the SurveyMonkey (SurveyMonkey Inc., San Mateo, California, USA, www.surveymonkey.com) platform, and administered both in-person ($n = 28$) and in an online format ($n = 51$). The in-person survey was distributed at the Montana Grain Growers Association Conference ($n = 11$) and the Montana Organic Association Conference ($n = 17$) in Great Falls, MT (November and December 2018, respectively). While the attendants of these two venues may have overlapped, each survey participant was unique. The online survey was distributed through USA Dry Pea and Lentil Council, Northern Pulse Growers Association, and University of Idaho Extension newsletters and/or distribution lists (open online December 2018–January 2019). The distribution of the surveys through these multiple types of agricultural organizations was carried out in order to elicit responses from a range of both organic and conventional lentil producers in Montana (USA), and the greater lentil producing regions in Idaho (USA), North Dakota (USA), Washington (USA), and Canada. The researcher did not make successful connections with Canadian-based pulse and/or lentil organizations, thus eliminating the opportunity to utilize an online platform to distribute the lentil producer survey more broadly to informants in Canada. In addition, the researcher did not travel outside of Montana (USA) thereby eliminating the opportunity to distribute the survey in-person in Canada, and additionally Idaho (USA), North Dakota (USA), and Washington (USA). Therefore, with the majority of producer informants located in Montana (USA), reference to Idaho (USA), North Dakota (USA), Washington (USA), and Canada as the "greater lentil producing region" outside of Montana (USA) is not meant to minimize the perceptions and observations of producers from these areas, but rather meant to account for small sample size from these participating areas.

Consumer Structured Questionnaire

Two structured questionnaires were designed, piloted, and implemented with consumers in Montana including a questionnaire for consumers who eat lentils several times a year (**Supplementary Material**: Survey for Consumers of Lentils) and a questionnaire for consumers who generally do not eat lentils (**Supplementary Material**: Survey for Consumers Who Do Not Eat Lentils). The surveys were designed based on review of the applicable literature (Bickel et al., 2000; Thornton and Cramer, 2012; Gundersen et al., 2017; Palmer et al., 2018). The consumer surveys were reviewed for face validity by content experts with expertise in sustainability, food systems, sustainable diets, nutrition, and health. Revisions were made to both versions of the consumer survey based on feedback from experts.

The final survey instrument for consumers who eat lentils included 23 multiple-choice, Likert-scale, and open-ended questions divided into the following five sections: (1) Individual/household consumption patterns, (2) Consumer knowledge, (3) Food security status, (4) Market policy, and (5) Comparison of lentils and animal-based protein sources. The survey for consumers who do not eat lentils consisted of 10 multiple-choice, Likert-scale, and open-ended questions divided into the following three sections: (1) Consumer knowledge, (2) Food security status, and (3) Comparison of lentils and animal-based protein sources. The background section of both survey instruments included questions to elicit demographic information including age range and food security status as well as questions to elucidate consumer understanding and/or perceptions of sustainability aspects of lentil consumption and production. Each survey instrument included a separate lentil brochure (**Supplementary Material**: Lentil Survey Brochure) for informants to utilize when answering the final section of the survey. The brochure included information regarding the environmental, economic, and nutritional aspects of lentils and animal-based protein sources. Informants had the option to choose between the two types of lentil consumer surveys on the basis of self-identified level of lentil consumption.

As for the producer survey, approval for human subjects to participate in this study was received from the Institutional Review Board (IRB) at Montana State and informed consent was obtained from all survey participants prior to completing the survey. The survey was administered at four locations (January–March 2019) in Gallatin and Park County (Montana, USA) that serve different types of consumers: (1) Bozeman Winters Farmers' Market (serves consumers that can generalized as supporters of local foods), (2) Heebs Fresh Market (local grocery that caters to a wide variety of consumer demographics), (3) Livingston Food and Resource Center (a food pantry and community kitchen that serves an economically vulnerable population), and (4) Montana State University Family Science Night (serves Bozeman-area families). The distribution of the surveys through these multiple locations was carried out in order to elicit responses from a range of consumers in Montana (USA) including both consumers and non-consumers of lentils.

Data Analysis

Producer Structured Questionnaire

A total of 79 producers completed, or partially completed, the survey from lentil producing areas in the USA and Canada. Participants with over 30% missing/incomplete responses were removed from the sample resulting in a final sample size of 63 informants. As not all informants responded to every question, sample size may vary among responses. Quantitative data was analyzed using the JMP (JMP® SAS Institute Inc., Cary, IL, USA) statistical software program. Analysis of Variance (ANOVA) and contingency analysis were carried out to compare differences among survey responses on the basis of the following three management practices: conventional management (n = 42), organic management (n = 15), and mixed management (n = 6; both conventional and organic management). The Pearson p-value is reported for significant differences in survey response among conventional, organic, and mixed management systems. Responses to open-ended questions were coded by two researchers following methods outlined in Saldana (2015). Coding involved development of a code book based on prevalent themes that emerged from responses. The coded responses were quantified and reported.

Consumer Structured Questionnaire

A total of 138 informants completed the survey including those who consume lentils (n = 70) and those who do not generally consume lentils (n = 68). As not all survey informants responded to every question, the sample size may vary among responses. As with the producer survey, consumer survey responses were analyzed using JMP statistical software. An ANOVA and contingency analysis were completed for survey responses between consumers who eat lentils and consumers who generally do not eat lentils. Further, analysis between lentil consumers was completed among groups with low, medium, and high frequency of lentil consumption. The Pearson p-value is reported for significant differences in survey response among consumers and non-consumers, as well as among low, medium, and high lentil consumption groups.

RESULTS

Producer Structured Questionnaire

Background of Lentil Production Systems

The majority of producers' farms (n = 62) were located in the Montana (USA) and accounted for 61% of informants, followed by 18% of producers located in Idaho (USA), 11% in Washington (USA), 3% in Saskatchewan (Canada), 2% in North Dakota (USA), 2% in Manitoba (Canada), and 3% with farms located in two or more states. Lentil production systems (n = 63) ranged among conventional management (n = 42; 67%), organic management (n = 15; 24%), and mixed management systems (n = 6; 10%). Producers reported total farm area (n = 59) ranged from ∼150 ha to about 10,000 ha with a mean farm size of 2,195 ha and standard deviation of 1,937 ha.

Producers' experience growing lentil (n = 61) ranged from 1 year to over 15 years. Producers reported they grew lentil for 1–5 years (36%), more than 15 years (33%), 6–10 years (20%), and 11–15 years (12%). Average land area dedicated to lentil production reported by producers (n = 62) ranged from <40 ha to >400 ha. Range of land area under lentil production reported by producers include 40–200 ha (29%), 200–400 ha (29%), >400 ha (23%), and 40 ha or less (19%). Producers reported they grow a variety of lentil including black, brown, French green, large/medium/small green, and red.

Environmental and Management Dimensions of Lentil Production Systems

The most prevalent management practices (**Figure 2**) reported by producers (n = 63) include dryland farming (83%), crop rotations (83%), and land rolling (76%). The least prevalent management practices reported by producers include cover cropping (16%), use of inorganic fertilizer (10%), and irrigation (3%). The practices that were significantly different among conventional, organic, and mixed management producers include use of chemical desiccant ($p < 0.0001$), no-tillage ($p = 0.007$), fungicide treated seed ($p < 0.0007$), tillage ($p = 0.0176$), swathing ($p < 0.0001$), organic certified ($p < 0.0001$), and cover cropping ($p < 0.0001$). Specifically, a greater number of conventional producers reported use of chemical desiccant (91%), no-tillage (86%), use of fungicide treated seed (93%), and tillage (46%) in contrast to organic and mixed management systems (**Figures 2E–H**). Alternately, a greater number of organic producers reported use of swathing (57%), organic certification (78%), and use of cover cropping (80%) in contrast to conventional and mixed management systems (**Figures 2J,L,M**).

The most prevalent perceptions of the agronomic effects (**Figure 3**) from including lentil in production reported by producers include that the addition of lentil helps transfer nitrogen to subsequent crops (68%), rhizobium inoculants are sufficient to ensure maximum nodulation in their lentil (68%), the addition of lentil helps increase nutrient availability for subsequent crops (65%), and helps increase overall food crop productivity (63%). The least prevalent perceptions of the agronomic effects reported by producers include the addition of lentil in production has decreased moisture availability for subsequent crops (17%), resulted from using no till management (16%), and producers have experienced inefficient nodulation in their lentil crop (16%). The differences in producers' perceptions of the agronomic affects from including lentil in their production system were not statistically significant among conventional, organic, and mixed management producers.

Agronomic rationale (**Figure 4A**) for including lentil in production systems was reported by producers. The most

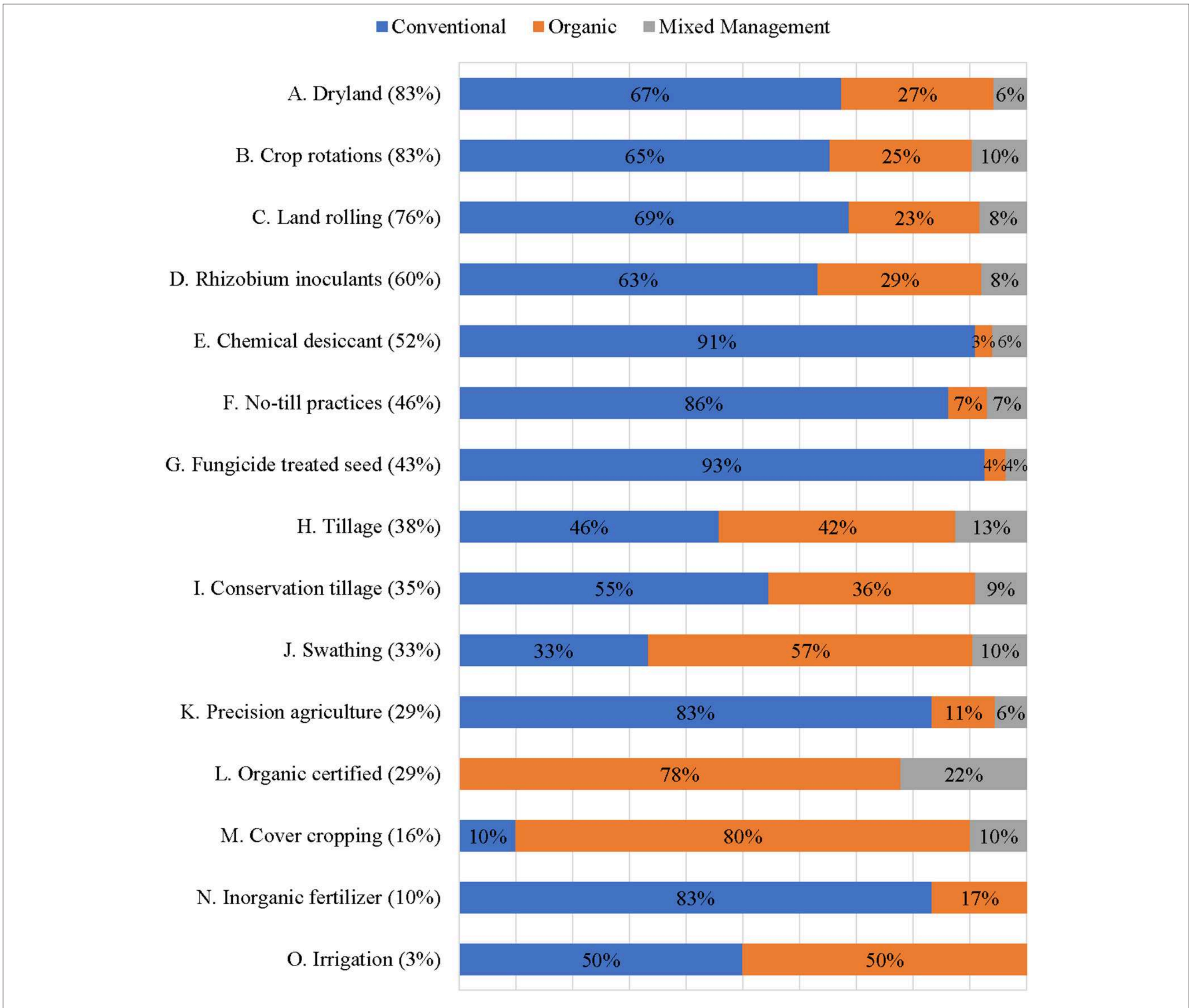

FIGURE 2 | Producers' management practices. Total percentage (shown in parenthesis) and the proportion of conventional, organic, and mixed management producers that reported using management practices including **(A)** dryland farming, **(B)** crop rotations, **(C)** land rolling, **(D)** rhizobium inoculants, **(E)** chemical desiccant, **(F)** no-tillage, **(G)** fungicide treated seed, **(H)** tillage, **(I)** conservation tillage, **(J)** swathing, **(K)** precision agriculture, **(L)** organic certification, **(M)** cover cropping, **(N)** inorganic fertilizer, and **(O)** irrigation ($n = 63$).

prevalent agronomic rationale reported by producers was to diversify crop rotation (92%), while the least prevalent rationale was to offset irrigation (0%). Agronomic rationale for including lentil in production systems that were significantly different among conventional, organic, and mixed management producers include lentil as green manure ($p = 0.0274$) and brown manure ($p = 0.0407$). Specifically, a greater number of organic producers reported use of lentil for green manure and brown manure compared to conventional and mixed management producers (**Figure 4A**).

Economic Dimension of Lentil Production Systems

The most prevalent range of on-farm income from lentil production and sales received over the past 10 years (2008–2017) reported by producers ($n = 61$) was between 6 and 15% (34%). Additionally, range of on-farm income received from lentil production reported by producers included <5% (28%), between 16 and 25% (25%), and >25% of on-farm income (13%). Significant differences in range of income were found among conventional, organic, and mixed management producers with conventional producers earning greater percentages of income from lentil production ($p = 0.0369$).

Producers reported ($n = 61$) their perceptions of market and policy factors that impacted lentil production during 2013–2017 (**Figure 5A**). The majority of producers reported tariffs and/or subsidies (72%) and market variability of lentil (67%) impacted their lentil production. The least prevalent perceived impacts of market and policy factors on lentil production during 2013–2017 reported by producers include cost of labor (16%) and fuel costs (13%). Producers' perceptions of effects of market

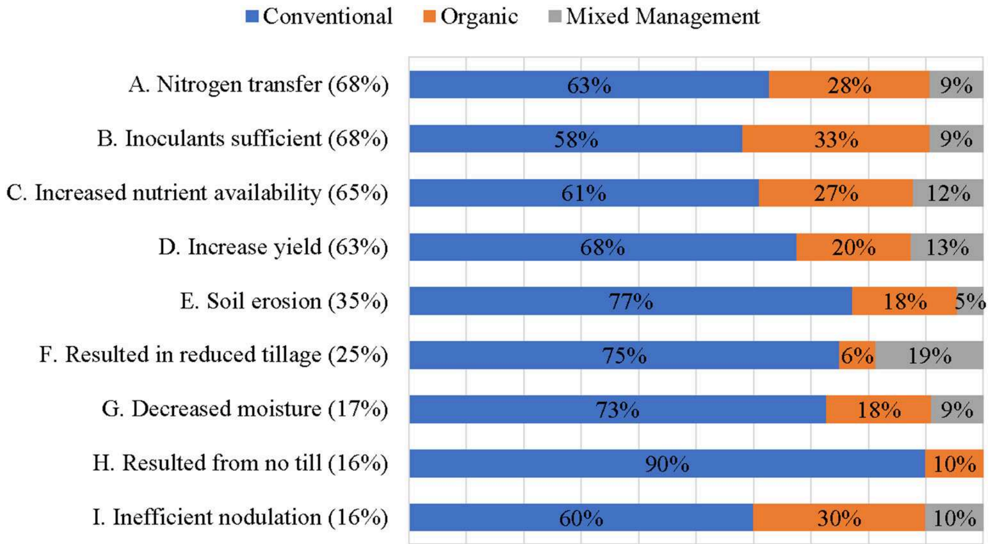

FIGURE 3 | Agronomic effects from lentil. Total percentage (shown in parenthesis) and the proportion of conventional, organic, and mixed management producers that reported agronomic affects that resulted from including lentil in production that include **(A)** nitrogen transfer to subsequent crop, **(B)** rhizobium inoculants sufficient, **(C)** increased nutrient availability for subsequent crops, **(D)** increased yield in overall food crop production, **(E)** soil erosion, **(F)** resulted in reduced tillage, **(G)** decreased moisture availability, **(H)** resulted from no-tillage, and **(I)** inefficient nodulation ($n = 63$).

and policy factors on lentil production that were significantly different among conventional, organic, and mixed management producers include tariffs and/or subsidies ($p < 0.0001$) and market variability ($p = 0.0308$). Specifically, a greater number of conventional producers reported tariffs and/or subsidies (82%) and market variability (76%) impacts lentil production in contrast to organic and mixed management producers.

Producers reported ($n = 61$) their perceptions of market access for lentil during 2013–2017 (**Figure 5B**). The majority of producers reported they had adequate access to a consistent market (79%), distribution channels (62%), and profitable market for lentil (59%). The differences in producers' perceptions regarding market access during 2013–2017 were not statistically significant among conventional, organic, and mixed management producers.

Producers reported their rationale and reasons for growing lentil related to economics (**Figure 4B**). The most prevalent economic rationale for growing lentil reported by producers include to capitalize on dryland production (95%) and to serve as a cash crop (87%). The economic rationale among conventional, organic, and mixed management producers that were significantly different include to grow lentil as a cash crop ($p = 0.0178$) and to offset herbicide cost or use ($p = 0.0384$). Specifically, a greater number of conventional producers reported they grow lentil as a cash crop (68%) and to offset herbicide costs (86%) in contrast to organic and mixed management producers.

Health Dimension of Lentil Production System

Producers reported their rationale for growing lentil related to health (**Figure 4C**). The majority of producers reported they grow lentil to support plant-based diets (52%). The least prevalent reason for growing lentil reported by producers was to support local food security (16%). The rationale for growing lentil related to health that were significantly different among conventional, organic, and mixed management producers include to support local food security ($p = 0.001$). Specifically, a greater number of organic producers reported they grow lentil to support local food security (70%).

With respect to the North American consumer (**Figure 6**), the most prevalent perception of consumer knowledge reported by producers ($n = 61$) include that consumers are generally knowledgeable regarding the nutrient benefits of lentils (34%). The least prevalent perception reported by producers include consumers are generally knowledgeable regarding how to incorporate lentils into their diets in a nutritionally balanced way (15%) and consumers are generally knowledgeable regarding how to cook with lentils (15%). Producers' perception of North American consumer knowledge that was significantly different include a greater number of conventional producers that reported consumers are generally knowledgeable regarding how to cook with lentils ($p = 0.0323$).

Global Change: Challenges and Opportunities

Producers reported environmental observations and weather affects that impact lentil production, and on-farm opportunities that include the potential for other crops. Environmental observations impacting lentil production reported by producers include drought stress (73%), extreme weather events (57%), pests and disease (46%), and increased temperatures (43%) (**Figure 7A**). Environmental observations impacting lentil production that were significantly different among conventional, organic, and mixed management producers include pests and disease ($p = 0.002$). Specifically, a greater number of

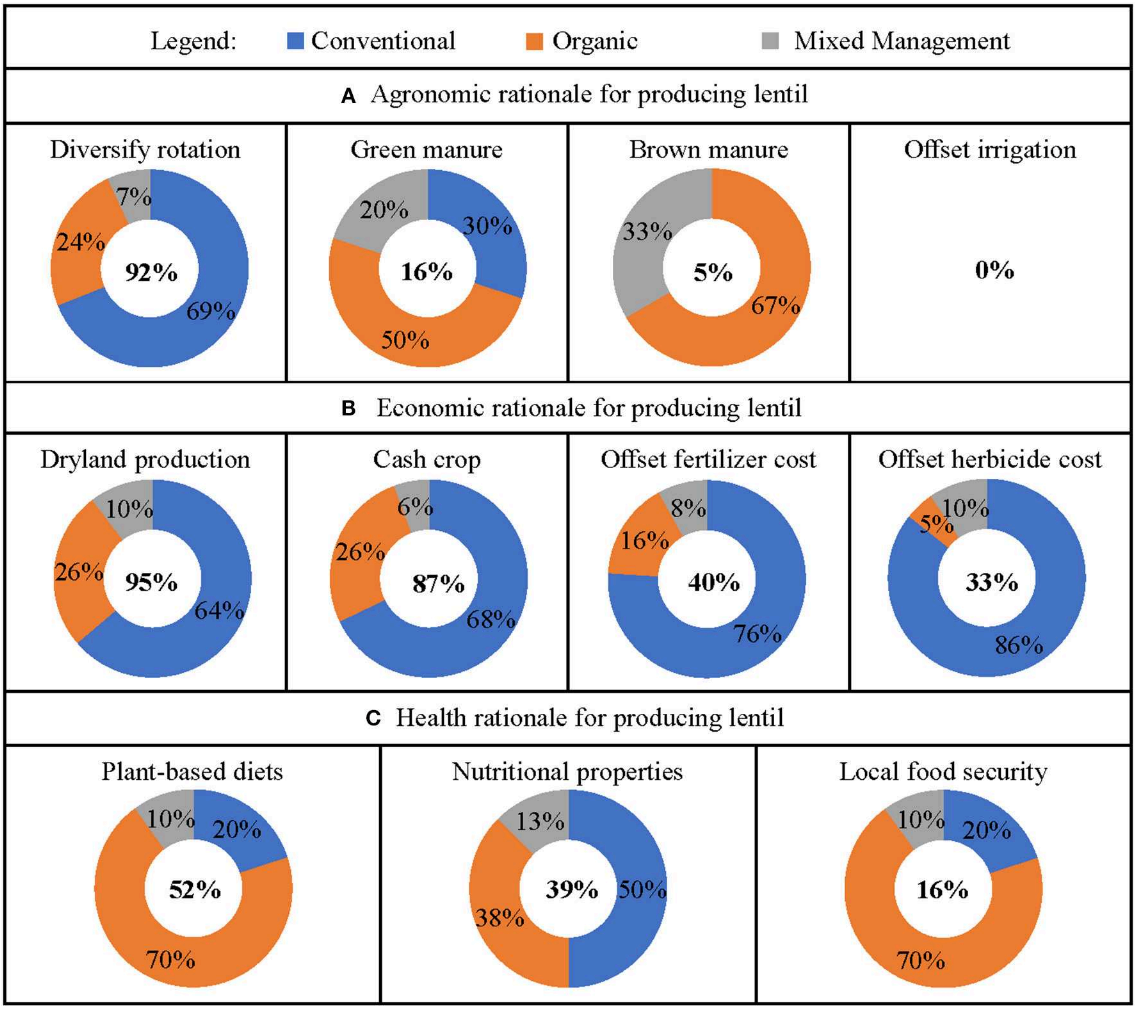

FIGURE 4 | Agronomic, economic, and health rationale. **(A)** Total percentage (center) and the proportion of conventional, organic, and mixed management producers that reported agronomic reasons ($n = 63$) for growing lentil that include to diversify crop rotation, green manure ($p = 0.0274$), brown manure ($p = 0.0407$), and to offset irrigation. **(B)** Total percentage (center) and the proportion of conventional, organic, and mixed management producers that reported economic for growing lentil that include to capitalize on dryland production, cash crop ($p = 0.0178$), offset fertilizer cost, offset herbicide costs ($p = 0.0385$). **(C)** Total percentage (center) and the proportion of conventional, organic, and mixed management producers that reported health reasons ($n = 61$) for growing lentil that include to support plant-based diets, nutritional properties, and to support local food security ($p = 0.001$).

conventional producers reported they observed pests and disease impact lentil production. Producers reported their perception of weather variation and extremes on their agricultural business on at least one or more occasion (**Figure 7B**). Half or more of producers reported El Niño or La Niña had an effect on their agricultural business (65%) and recent changes in climate due to normal weather cycles had an effect on their agricultural business (50%). A minority of producers reported they had not experienced of the effects of weather variation and weather extremes on their agricultural business (8%). Producers' views regarding the effect of climate change were significantly different among conventional, organic, and mixed management producers ($p = 0.0012$). Specifically, a greater number of organic producers reported climate change had an effect on their agricultural business (50%) in contrast to convention and mixed management producers.

Producers reported their perceptions of extreme weather patterns and/or climate change on future lentil crop yield and change in areal crop rotation over the next 20 years. The most prevalent perceptions reported by producers include they expect average lentil yield will stay the same (45%). The least prevalent perception reported by producers include they expect a decrease (16%) in lentil crop yield. Perceptions regarding whether or not other area producers would make a significant change in crop rotation due to extreme weather patterns and/or climate change in the next 20 years reported by producers include they are not sure (38%), there will be no change (32%), and yes, there will be a change (30%). The differences between producers'

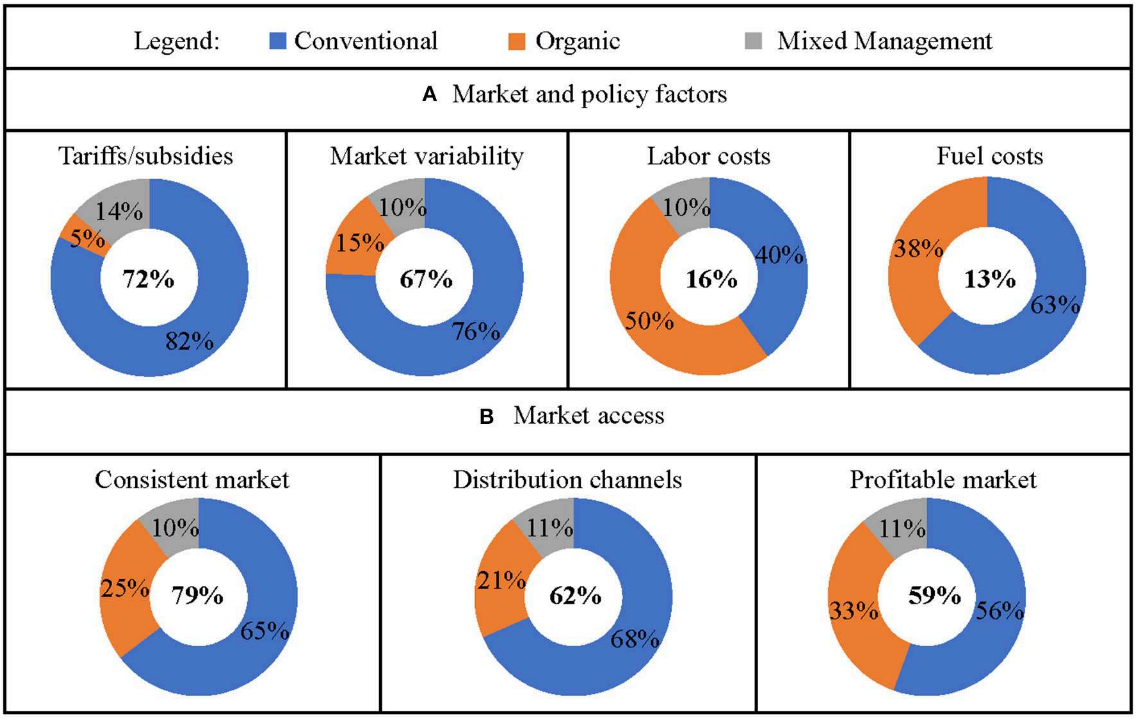

FIGURE 5 | Market, policy, and market access. **(A)** Total percentage (center) and the proportion of conventional, organic, and mixed management producers that reported market and policy factors that affect lentil production including tariffs/subsidies ($p < 0.0001$), market variability ($p = 0.0308$), labor costs, and fuel costs. **(B)** Total percentage (center) and the proportion of conventional, organic, and mixed management producers that reported market access for lentil that includes adequate access to a consistent market, distribution channels, and profitable market ($n = 61$).

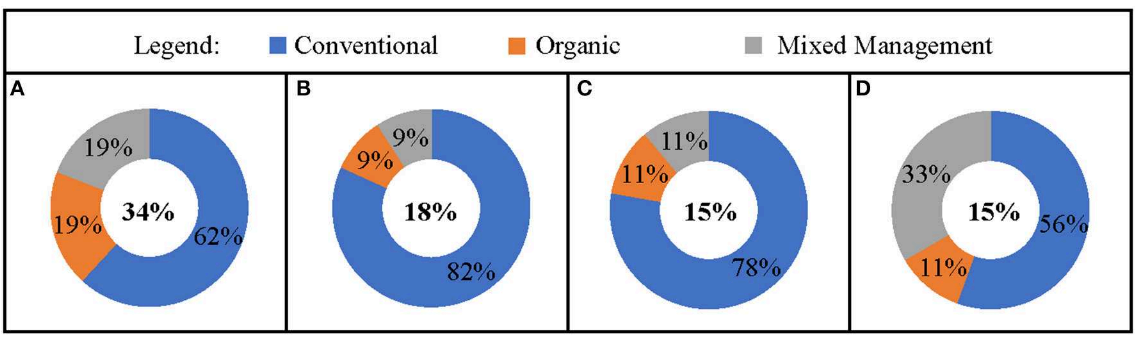

FIGURE 6 | Producers' perception of the North American consumer. Total percentage (center) and the proportion of conventional, organic, and mixed management producers that reported their perceptions of the North American consumer with respect to their views and knowledge of lentils including **(A)** nutrient benefits, **(B)** find taste desirable, **(C)** how to incorporate lentils in diet with nutritional balance, and **(D)** how cook with lentils ($p = 0.0323$) ($n = 61$).

perception regarding weather impacts on future lentil crop yield and areal changes in crop rotation over the next 20 years were not statistically significant among conventional, organic, and mixed management producers.

With respect to the rising cost of energy, producers reported they would consider making relatively few on-farm changes in the next season or near future specifically related to alternative energy sources such as biofuels and/or land-use change (**Supplementary Figure 1**). While the minority of producers reported they would consider any of the select changes, the most prevalent response reported by producers include they would change their management practices (28%). The least prevalent changes reported by producers include they would try to develop a local market for biofuels (2%) and use alternative fuels available on the market (0%). Producers' consideration of on-farm changes that were significantly different among conventional, organic, and mixed management producers include exploring alternative energy sources such as wind or solar

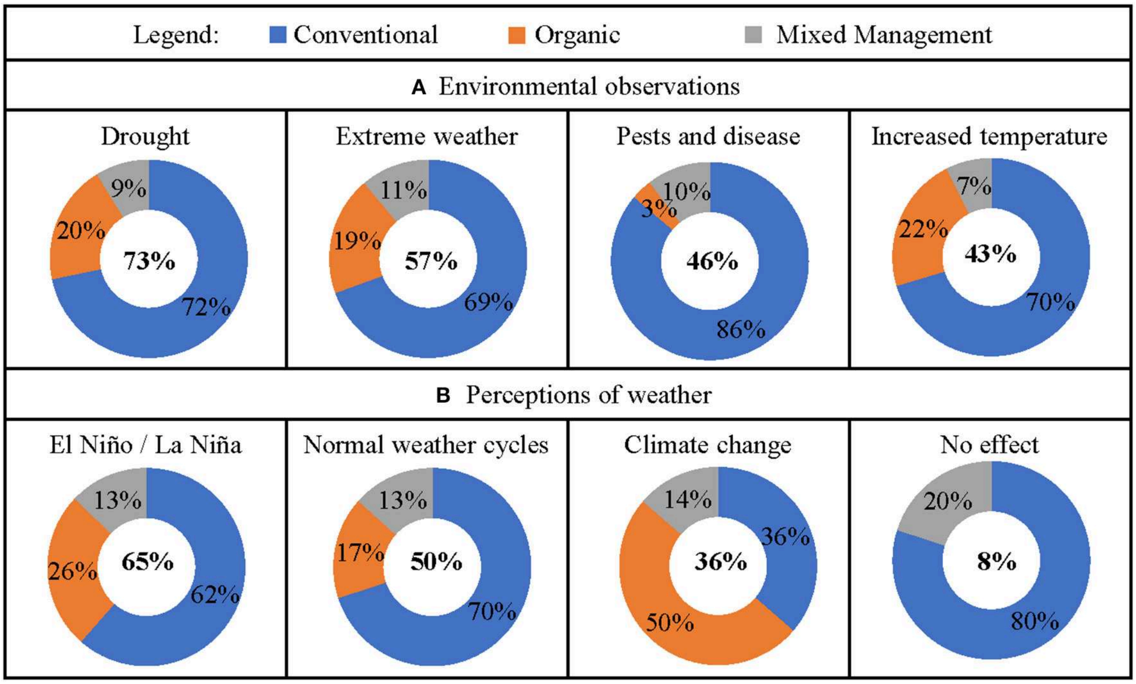

FIGURE 7 | Environmental observations and perceptions of weather. **(A)** Total percentage (center) and the proportion of conventional, organic, and mixed management producers that reported environmental observations ($n = 63$) that have impacted lentil production including drought, extreme weather, pests and disease ($p = 0.002$), and increased temperature. **(B)** Total percentage (center) and the proportion of conventional, organic, and mixed management producers that reported effects of weather ($n = 60$) that have had an impact on their agricultural business including the cyclical weather patterns El Niño and/or La Niña, normal weather cycles and variation, climate change ($p = 0.0012$), and no effect of weather variation or extremes on their agricultural business.

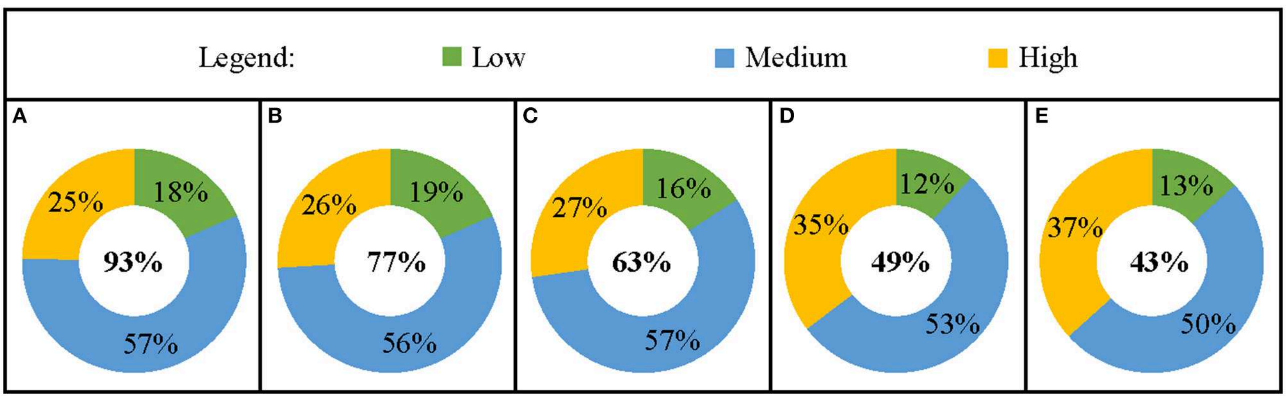

FIGURE 8 | Consumer rational for eating lentils. Total percentage (center), and proportion of low, medium, and high lentil consumption groups that reported their rationale for eating lentils based on **(A)** nutritional properties, **(B)** affordability, and to support **(C)** a plant-based diet, **(D)** the environment, and **(E)** local farmers ($n = 70$).

($p = 0.0002$). Specifically, a greater number of organic producers reported they would consider exploring alternative energy such as wind and solar (73%) compared to conventional and mixed management producers (**Supplementary Figure 1**).

With respect to the rising cost of energy, producers reported the feasibility of alternative crops and products they perceived as having potential for success to help meet local, regional, and/or national future energy needs (**Supplementary Figure 2**). Generally, the most prevalent crops perceived as feasible to help meet energy needs reported by producers include perennial grasses (33%) and cellulosic biomass (30%). The least prevalent alternatives perceived as feasible to help meet energy needs reported by producers include plant wastes (23%) and algal biofuels (17%). The crops and products perceived as feasible to help meet energy needs reported by producers that were significantly different among conventional, organic, and mixed

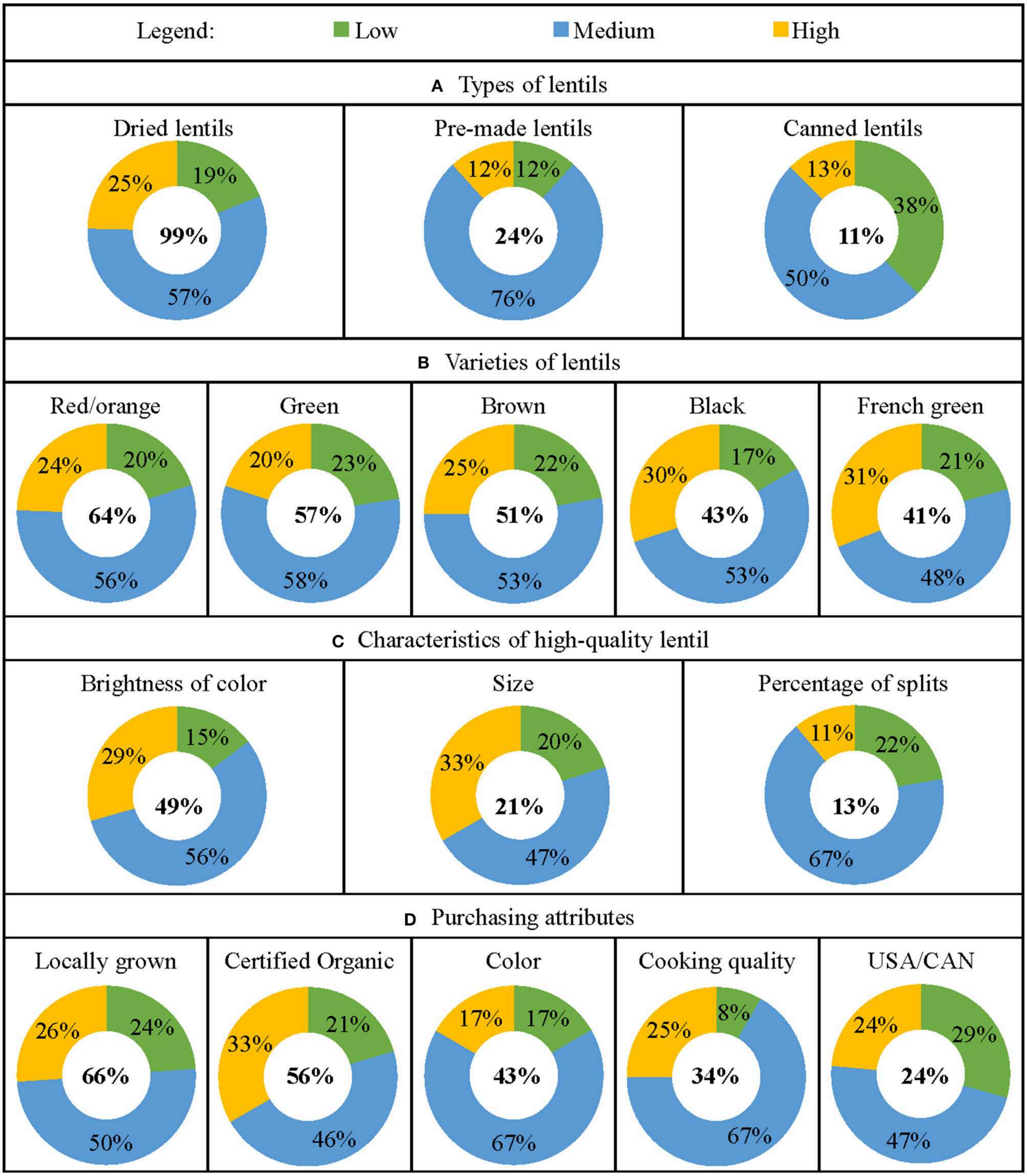

FIGURE 9 | Purchasing attributes and lentil characteristics. **(A)** Total percentage (center), and proportion of low, medium, and high lentil consumption groups that reported lentil characteristics that influence purchasing decisions based on lentil types including dried lentils, pre-made lentil meals, and canned lentils. **(B)** Total percentage (center), and proportion of low, medium, and high lentil consumption groups that reported lentil characteristics that influence purchasing decisions based on lentil varieties including red/orange, green, brown, black, and French green. **(C)** Total percentage (center), and proportion of low, medium, and high lentil consumption groups that reported characteristics that constitute a high-quality lentil including brightness of color, size, and percentage of splits. **(D)** Total percentage (center), and proportion of low, medium, and high lentil consumption groups that reported lentil attributes that influence purchasing decisions including locally grown or grown in Montana (USA), certified organic, color, cooking qualities, and grown in the United States or Canada ($n = 70$).

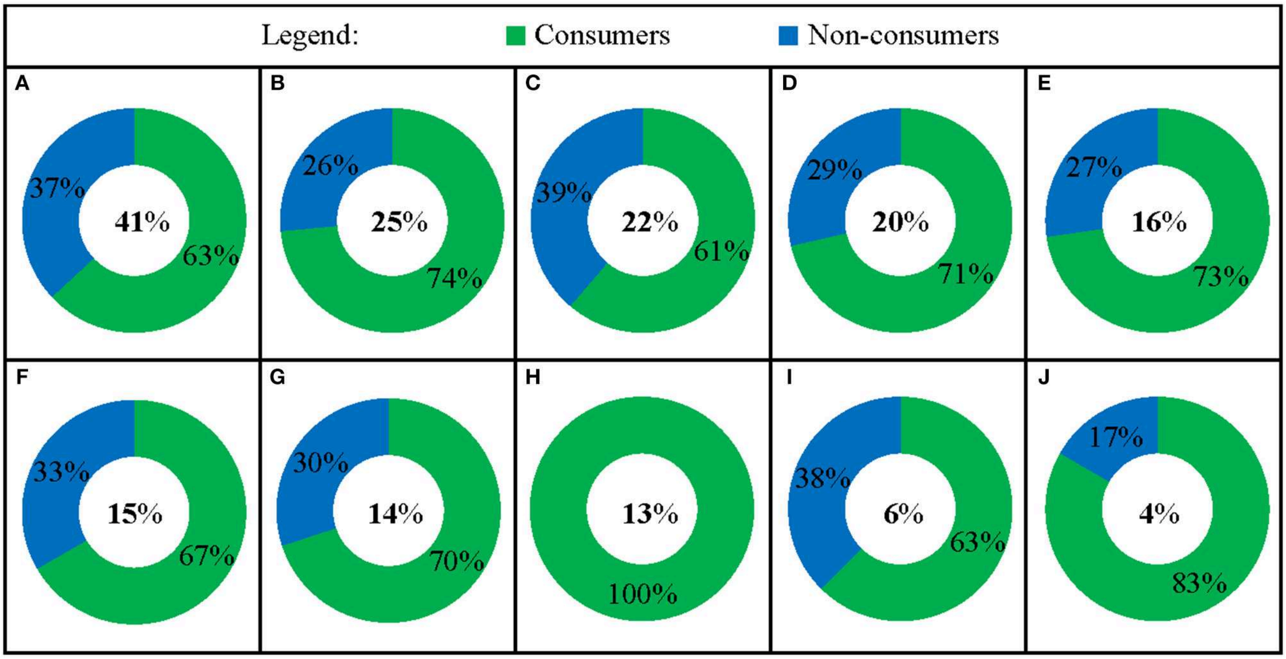

FIGURE 10 | Sources of lentil information. Percentage of all informants (center) and proportion of lentil consumers and non-consumers that reported they receive information on lentils from **(A)** family and/or friends ($p = 0.0143$), **(B)** the internet ($p = 0.0022$), **(C)** community programs and/or extension, **(D)** health magazines ($p = 0.0141$), **(E)** farmers' market ($p = 0.0244$), **(F)** Dietary Guidelines, **(G)** local food cooperative, **(H)** farmers ($p < 0.0001$), **(I)** supermarket, and **(J)** doctor and/or dietician ($n = 138$).

management producers include corn for ethanol ($p = 0.0149$) and biodiesel from small grains ($p = 0.0115$). Specifically, in contrast to organic and mixed management producers, a greater number of conventional producers reported feasibility of corn for ethanol and biodiesel from small grains.

With respect to the rising cost of energy and the feasibility of alternative crops and products to help meet future energy needs, producers reported a variety of factors that would influence their decision to grow an energy crop in the next season or the near future (**Supplementary Figure 3**). The majority of producers reported the factors that would influence their decision to grow an energy crop include improving soil quality and/or building organic matter (72%) and market potential for the crop (70%). The least prevalent factors reported by producers include reducing carbon dioxide emissions (18%) and to create jobs in the community (18%). Factors that would influence producers' decisions to grow an energy crop that were significantly different among conventional, organic, and mixed management producers include concern about using resources for food vs. fuel ($p = 0.034$) and reducing carbon dioxide emissions ($p = 0.0327$). Specifically, a greater number of organic producers reported concern about using resources for food vs. fuel (47%) and reducing carbon dioxide emissions (55%).

Producers identified current management challenges for lentil production and concerns for future lentil production. The three most prevalent challenges reported by producers include challenges with (1) weeds and other pests, (2) lentil harvest, and (3) weather. The three most prevalent concerns identified regarding future lentil production reported by producers include (1) market demand and price of lentil, (2) weeds and pests, and (3) weather.

Producers identified the main agronomic reasons they value including lentil in their production system and opportunities for future lentil production. The three most prevalent agronomic reasons reported by producers include they value (1) the rotational benefits from lentil, (2) price of lentil, and (3) nitrogen fixation. The three most prevalent opportunities for future lentil production reported by producers include increase in (1) consumer knowledge and domestic demand, (2) market and price, and (3) research related to new plant varieties.

Consumer Structured Questionnaire

Demographics

Informants ($n = 138$) participated in the lentil consumer survey at locations that included the Bozeman Winter Farmers' Market (41%), Heebs Fresh Market (26%), Livingston Food Resource Center (25%), and Montana State University Family Science Night (8%). Informants reported their age range was between 18–37 years (45%), 38–54 years (25%), 55–73 years (26%), and 74–92 years of age (4%).

Informants self-selected one of the two surveys based off their own/household frequency of lentil consumption that included (1) Survey for Consumers of Lentils (**Supplementary Material**) and (2) Survey for Consumers Who Do Not Eat Lentils (**Supplementary Material**). Informants that self-reported they/their household do/does not generally eat lentils accounted for 49% of informants (herein "non-consumers"). Informants that self-reported they/their household eat/eats lentils (lentils consumed at least a few times to numerous times per year) accounted for 51% of informants (herein "consumers"). Of the self-reported lentil consumers, 20% reported they eat lentils several times a year (herein "low" frequency group), 56% reported they eat lentils around once per week (herein "medium" frequency group), and 24% reported they eat lentils as a regular part of their diet (herein "high" frequency group).

Two questions were selected from U.S. Household Food Security Survey Module: Six-Item Short Form of the Food Security Survey Module (US Department of Agriculture, Economic Service Research, 2012) based on their sensitivity, specificity, and accuracy to detect indication of food insecurity (Gundersen et al., 2017). Informants were asked to report their level of agreement (often, sometimes, or never true) with the following statements, (1) "We worried whether (my/our) food would run out before (I/we) got money to buy more" and (2) "The food that (I/we) bought just didn't last and (I/we) didn't have money to get more" ($n = 137$). Overall, 23% of informants reported affirmative responses that indicate food insecurity, with an approximately even split between lentil consumers (12%) and non-consumers (11%).

Individual Consumption Patterns

The following section on individual consumption patterns includes responses from informants that consume lentils (consumers; $n = 70$). Change in household lentil consumption over the past 5 years reported by consumers include an increase (59%), no change (36%), and a decrease in lentil consumption (4%). The most prevalent rationale for eating lentils (**Figure 8**) reported by consumers include they eat lentils for their nutritional properties (93%), affordability (77%), and to support a plant-based diet (63%). The differences in consumers' change in household lentil consumption and rationale for eating lentils were not statistically significant among low, medium, and high lentil consumption groups.

Consumers reported they are interested in several attributes when purchasing lentils (**Figure 9**). The most prevalent type and variety of lentils purchased that was reported by consumers include dried lentils (99%) and red/orange lentils (64%). The most prevalent perception of what constitutes high-quality lentils reported by consumers was brightness of color (49%). Purchasing decisions related to social values and quality attributes of lentils reported by the majority of consumers include preference for locally grown (grown in Montana) (66%) and certified organic lentils (56%). Significant differences in lentil attributes were not found among low, medium, and high lentil consumption groups.

Consumer Knowledge

The following section on consumer knowledge includes responses from both consumer and non-consumer groups ($n = 138$). The most prevalent sources of lentil information reported by informants include family and friends (41%) followed by the internet (25%) (**Figure 10**). The least prevalent sources of lentil information reported by informants include supermarket (6%) and a doctor and/or dietician (4%). There were similarities and differences in sources of information on lentils between consumers and non-consumers. The sources of lentil information reported by informants that were significantly different between consumers and non-consumers of lentils include family and/or friends ($p = 0.0143$), the internet ($p = 0.0022$), health magazines ($p = 0.0141$), farmers market ($p = 0.0244$), and farmers ($p < 0.0001$). For all differences noted, consumers reported a greater prevalence of lentil information from the select sources compared to non-consumers.

Informants reported their agreement with statements regarding knowledge and perceptions of lentils (**Figure 11**). The majority of all informants agreed they find the taste of lentils desirable (73%) and they feel knowledgeable regarding the nutrient benefits of lentils (51%). Significant differences between consumers and non-consumers include that they find the taste of lentils desirable ($p = 0.0028$), they feel knowledgeable regarding the nutrients benefits of lentils ($p < 0.0001$), how to cook with lentils ($p < 0.0001$), how to incorporate lentils into their diet in a nutritionally balanced way ($p < 0.0001$), and how to use the different types of lentils into a variety of dishes ($p < 0.0001$). For all differences noted, lentil consumers reported a greater prevalence of agreement regarding knowledge and perceptions of lentils than non-consumers.

Informants reported their level of agreement with statements regarding health and nutritional aspects from including lentils in diet with a 5-point Likert scale from "strongly agree" to "strongly disagree" (**Figure 12**). The majority of informants reported they either agreed or strongly agreed lentils can help to improve nutrition (88%), feel satiated or full (85%), support a plant-based diet (81%), promote a healthy digestive tract (77%), benefit weight loss efforts (59%), maintain healthy blood sugar (59%), and lower bad cholesterol (51%). Differences between consumers' and non-consumers' reported level of agreement on the health and nutritional aspects of including lentils in diet include lentils help to improve nutrition ($p < 0.0001$), feel satiated or full ($p < 0.0001$), support plant-based diets ($p < 0.0001$), promote a healthy digestive tract ($p < 0.0001$), maintain healthy blood sugar ($p < 0.0001$), benefit weight loss efforts ($p = 0.0035$), lower bad cholesterol ($p = 0.0006$), produces gas ($p = 0.0395$), and benefit the diet of those with diabetes ($p = 0.0007$). For all differences noted, lentil consumers reported a greater prevalence of agreement regarding knowledge and perceptions of lentils than non-consumers.

Market and Access

The following section on market and access includes responses from informants that consume lentils (consumers; $n = 70$). The most prevalent locations consumers reported they purchase lentils include supermarket (83%) and farmers' market and/or co-operative (74%). The least prevalent location consumers reported they purchase lentils include big box stores (11%). The majority of consumers reported they agree lentils are generally available at the market of their choice (99%) and affordable or sold at a reasonable price (97%) (**Figure 13**). Consumers reported they agree they have adequate access to lentils of all types (black, brown, green, French green, and red/orange) in their community (82%). Additionally, consumers reported they agree the lentils

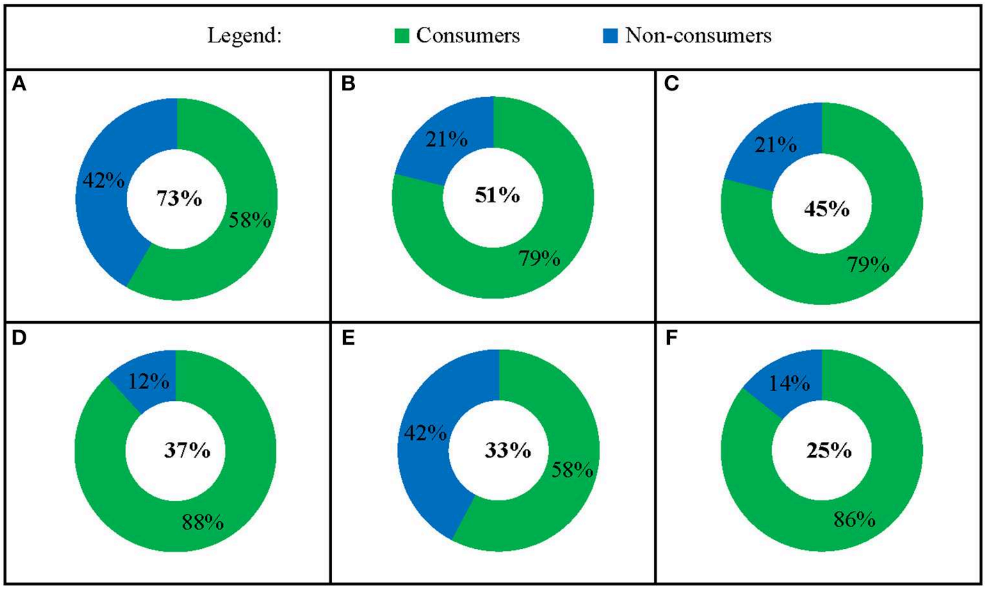

FIGURE 11 | Consumer knowledge and perceptions of lentils. Percentage of all informants (center) and proportion of lentil consumers and non-consumers that reported they **(A)** find the taste of lentils desirable ($p = 0.0028$), **(B)** feel knowledgeable regarding the nutritional benefits of lentils ($p < 0.0001$), **(C)** feel knowledgeable regarding how to cook with lentils ($p < 0.0001$), **(D)** feel knowledgeable regarding how to include lentils in their diet in a nutritionally balanced way ($p < 0.0001$), **(E)** agree that lentils are classified as both a protein and a vegetable in the 2015 Dietary Guidelines for Americans, and **(F)** they feel knowledgeable regarding how to use different lentils in a variety of dishes ($p < 0.0001$) ($n = 138$).

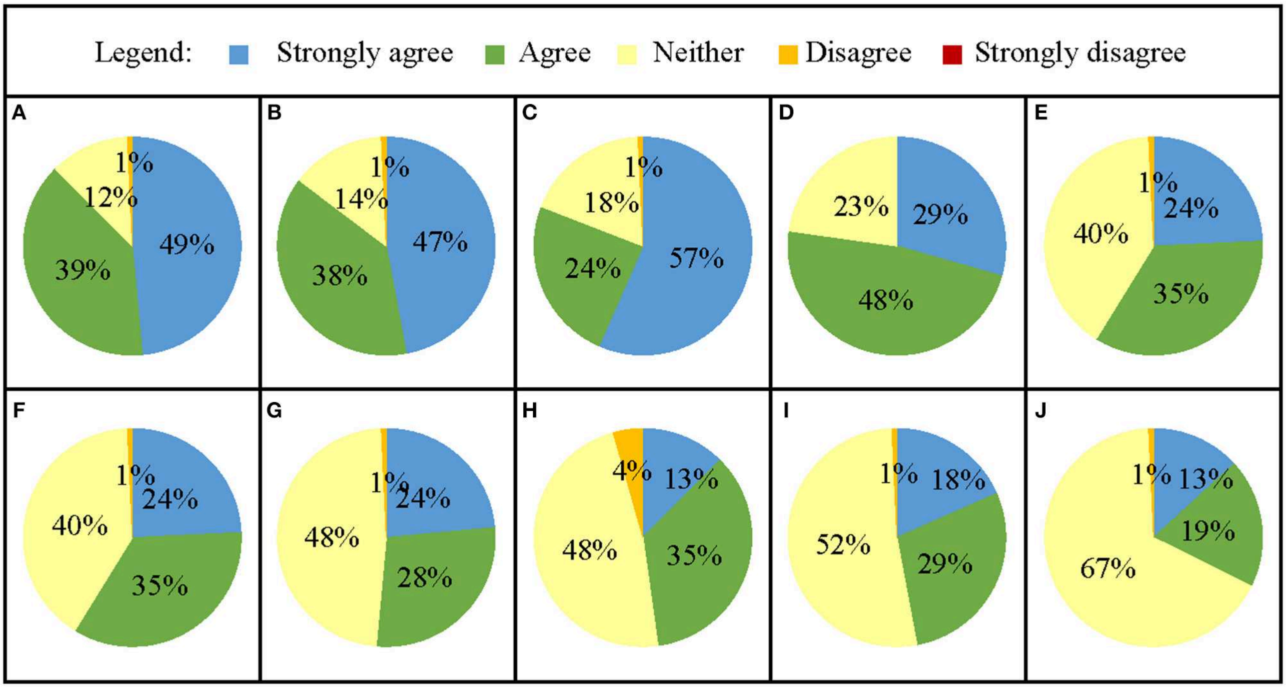

FIGURE 12 | Consumer knowledge and perceptions of health. Total informant level of agreement with health and nutritional statements regarding the effects of including lentils in their diet to help **(A)** improve nutrition ($p < 0.0001$), **(B)** feel satiated or full ($p < 0.0001$), **(C)** support plant-based diets ($p < 0.0001$), **(D)** promote a healthy digestive track ($p < 0.0001$), **(E)** maintain healthy blood sugar ($p < 0.0001$), **(F)** benefit weight loss efforts ($p = 0.0035$), **(G)** lower bad cholesterol ($p = 0.0006$), **(H)** produce gas ($p = 0.0395$), **(I)** benefit diet of those with diabetes ($p = 0.0007$), and **(J)** reduce cancer risk ($n = 138$). Significant differences are between lentils consumers and non-consumers ($n = 136$).

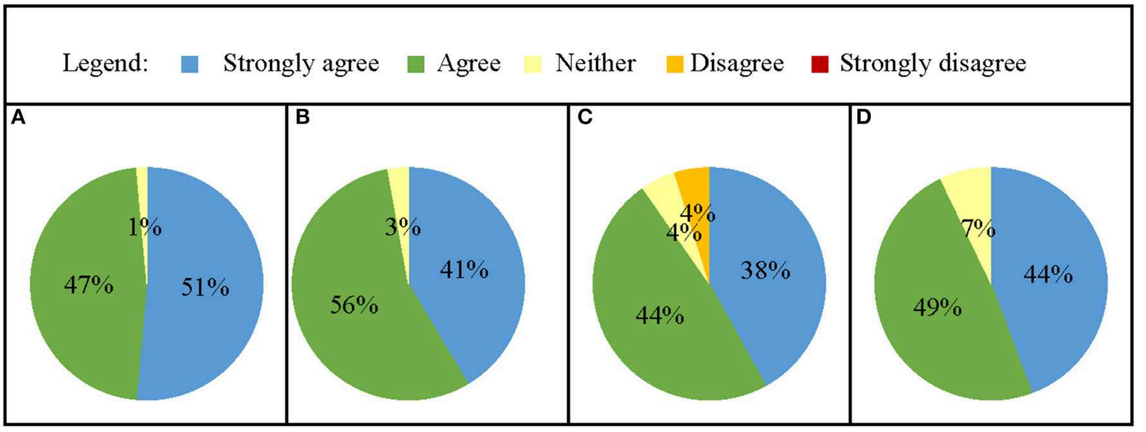

FIGURE 13 | Consumers' market access. Total informant level of agreement with statements regarding market and access of lentils reported by informants that include **(A)** lentils are readily available at the market of our choice, **(B)** lentils are sold at an affordable and reasonable price, **(C)** lentils of all types are accessible in the community, **(D)** the lentils purchased meet expectations on the basis of taste, aroma, texture, and palatability ($n = 70$).

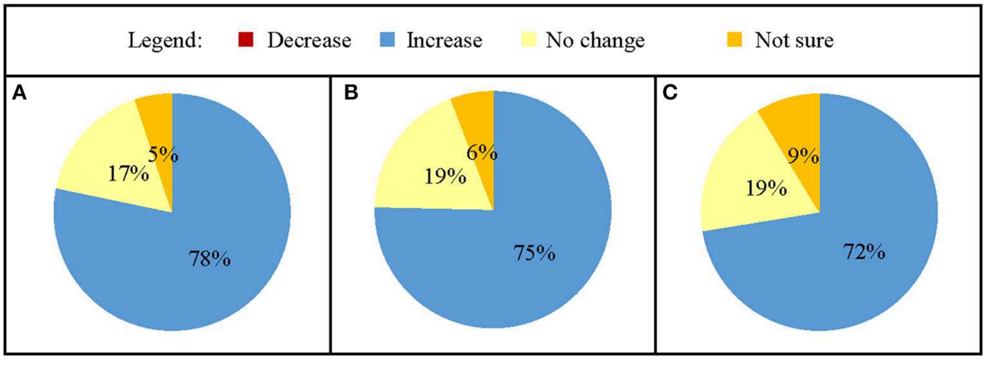

FIGURE 14 | Consumers' perception of the environmental, economic, and nutrition information on lentils. Percentage of informants that reported they would change their current lentil consumption based on **(A)** environmental, **(B)** economic, and **(C)** nutritional ($p = 0.0103$) information on lentils ($n = 138$).

they purchase generally meet their quality standards on the basis of taste, aroma, texture, palatability (93%). The differences between consumers' rationale regarding market and access of lentils and frequency of consumer lentil consumption among low, medium, and high groups were not statistically significant.

Lentil Brochure and Willingness to Change Consumption Patterns

The following section on consumer knowledge and willingness to change amount and/or frequency of lentil consumption includes responses from both consumer and non-consumer groups ($n = 138$). Informants were presented with a lentil brochure (**Supplementary Material**: Lentil Survey Brochure) with information on the environmental, economic, and nutritional aspects of protein production that compared lentils and animal-based protein sources. Informants reported their willingness to change their lentil consumption frequency based off information from the lentil brochure (**Figure 14**). Regardless of lentil consumption, consumers and non-consumers reported they would increase the amount or frequency in which they consume lentils based on the environmental (78%), economic (75%), and nutrition (72%) information contrasting lentils and animal-based protein sources. The differences between consumers' and non-consumers' willingness to change their frequency of lentil consumption that were significantly different included the nutritional information ($p = 0.0103$). A greater prevalence of non-consumers reported they were not sure, and a greater prevalence of consumers reported they would not change their frequency of consumption, based off the nutritional information.

DISCUSSION

Key Findings

This study elucidates perceptions of lentil producers and consumers and highlights the contribution of lentil production and consumption to the sustainability profile of lentil in Montana and the surrounding lentil-producing regions. On the production side of the lentil system, producers from all management types reported environmental, socio-economic, and health aspects related to lentil production that include they grow lentil to diversify crop rotations (92%), capitalize on dryland production (95%), and as a cash crop (87%), and half of producers reported they grow lentil to support a plant-based diet (52%). On the consumption side of the lentil system, lentil consumers generally were more knowledgeable about lentils, and eat lentils due to their nutritional properties (93%), affordability (77%), and to support plant-based diets (63%). Lentil consumers and non-consumers alike reported they would increase their lentil consumption based on environmental (78%), economic (75%), and nutritional (72%) information contrasting lentils and animal-based proteins.

Producers

Similarities among conventional, organic, and mixed management producers point to the overall sustainability of lentil production in the food system. For example, the majority of producers reported certain perceptions and practices regarding lentil production that contribute to the environmental, socio-economic, and health dimensions of sustainability. Environmental aspects include lentil helps diversify crop rotations (92%), nitrogen transfer to subsequent crop (68%), increase nutrient availability for subsequent crop (65%), and increase yield of subsequent food crops (63%). Socio-economic aspects include producer perceptions and practices that lentil production results in savings in input costs such as fertilizer (40%) and herbicide (33%), income as a cash crop (87%), adequate access to a consistent (79%) and profitable market (59%), and distribution channels (62%). In addition, lentil production contributes to the health aspects of sustainability through support of plant-based diets (52%) while providing consumers access to an affordable plant-based protein source. Alternately, very few producers reported use of inorganic fertilizer (10%) and irrigation (3%) that point to the low-input nature of lentil production in the study region.

Differences among conventional, organic, and mixed management producers in this study highlight areas where one management type may be more beneficial or resilient in certain aspects of sustainability than another. Specifically, of those that reported each respective management practice or perception, conventional producers more prevalently reported use of no-till (86%) and received greater on-farm income from lentil production (78%). In addition, of those that reported each respective perception of market effect and environmental observation on lentil, conventional producers more prevalently reported impacts of tariffs and/or subsidies (82%) and market variability (76%), and effects of drought (72%), extreme weather (69%), pests and disease (86%), and increased temperatures (70%). This points to both positive outcomes in soil carbon sequestration and on-farm income through lentil production, and barriers to lentil production through policy and market effects, and effects of weather and pests and disease experienced by conventional producers. Alternately, of those that reported each respective management practice, organic producers more prevalently reported swathing (57%), in contrast to use of chemical desiccant reported by conventional producers (91%). In addition, of those that reported each respective perception of market effect and environmental observation on lentil, organic producers less prevalently reported impacts of tariffs and/or subsidies (5%) and market variability (15%), and effects of drought (20%), extreme weather (19%), pests and disease (3%), and increased temperatures (22%). This leads to a potential "resilience effect" experienced by organic producers shown by less prevalently reported impacts of policy and market effects, and effects weather and pest and disease on their lentil crop (Carlisle, 2014).

At a local level, relatively few producers reported they grow lentil to support local food security, however, food security is supported at a regional and/or global level through lentil export. Producers perceive North American consumers are not generally knowledgeable regarding health and nutritional aspects of lentils shown by 15–34% of producers that reported they feel consumers are knowledgeable regarding specific aspects of lentil. This highlights an opportunity for producers to learn consumer perceptions and purchasing habits as well as barriers to local consumption, such as lack of consumer knowledge of lentil.

Consumers

Similarities in perceptions and knowledge of lentils between lentil consumers and non-consumers were relatively few. Among all informants, the least reported source of lentil information was from a doctor/dietician (4%), and relatively few informants reported they receive lentil information from dietary guidelines (15%). This highlights an opportunity for education efforts to include individuals in health professions to promote lentils as a part of a healthy eating pattern, as described in the dietary guidelines, in addition to promoting education efforts about the dietary guidelines in school health classes and other appropriate settings. Another similarity between consumers and non-consumers include their willingness to increase lentil consumption based on environmental (78%), economic (75%), and health and nutrition (72%) information of lentils. This points to the educational opportunities to increase regional consumption through promoting sustainability dimensions that are supported through lentil production and consumption. Similarities among consumers that eat lentils were prevalent. For example, lentil consumers among low, medium, and high consumption groups reported they eat lentils for their nutritional properties (93%), affordability (77%), and to support a plant-based diet (63%). While less than the majority, but of similar note, consumers reported they eat lentils to support the environment (49%) and local farmers (43%). In addition, consumers reported they purchase locally grown (66%) and organic (56%) lentils. This points to the awareness of sustainability among lentil consumers in the food system and leads to the impression that awareness of sustainability principles may promote lentil consumption.

Differences in knowledge and perceptions between consumers and non-consumers of lentils were more prevalent. Of those that reported knowledge aspects regarding lentils, relatively few non-consumers reported they feel knowledgeable regarding the nutritional benefits of lentils (21%), how to cook with lentils (21%), and how to include lentils in their diet in a nutritionally balanced way (12%). Non-consumers also more prevalently reported uncertainty in agreement with health aspects regarding lentils such as lentils help improve nutrition, maintain healthy blood sugar, promote a healthy digestive tract, benefit diet of those with diabetes, lower bad cholesterol, and reduce cancer risk. This points to a gap in education and knowledge on the benefits of lentils that are available to consumers, and highlights opportunity to increase access and consumption through outreach efforts directed at consumers, and especially populations vulnerable to food insecurity such as those who participate in federally funded food programs and local food banks and food distribution centers.

Limitations

With respect to the lentil producer survey, limitations include sample size and distribution, response bias, and spatial scale. The results in this study apply to producers in the United States, and Canada, to a minimal extent. Specifically, the majority of producers that participated in the producer survey have farm locations in Montana (61%), followed by Idaho (18%), Washington (11%), Canada (5%), North Dakota (2%), and <4% of producers had locations in more than one state. Regional differences could not be elucidated due to small sample sizes across areas outside of Montana (USA). The researcher did not make successful connections with Canadian-based pulse and/or lentil organizations, thus eliminating the opportunity to utilize an online platform to distribute the lentil producer survey more broadly to producers in Canada. Additionally, the researcher did not travel outside of Montana (USA) thereby eliminating the opportunity to distribute the survey in-person in Canada, as well as Idaho (USA), North Dakota (USA), and Washington (USA). Another limitation with respect to sample size and distribution include that organic producers were oversampled by a magnitude several times greater than conventional producers, especially considering organic farmland in the United States is <1% of total farmland in USA (United States Department of Agriculture (USDA) Economic Research Service, 2011). Another limitation in the producer survey is response bias among producers that completed the survey. Additionally, the spatial scale is reported at the state/country level, where-as county-level regions may have further emphasized differences, such as climatic responses of lentil.

Limitations of the consumer survey include scale of survey distribution and sample bias, as well as response bias. The survey results may only apply at a localized level within Gallatin and Park County, Montana. However, the survey was distributed to diverse populations at a local grocery, farmers' market, food resource center, and a university-related family event with a wide range of informants with demographic differences. Another limitation of the consumer survey is the potential bias introduced by informants that completed the survey. If another region in Montana, or region in the United States or Canada was sampled, results may be similar or could substantially vary. For example, if the survey was distributed in other college towns and smaller urban centers located in rural states and provinces, results may be similar. In contrast, if the survey was completed on an American Indian reservation, or predominately rural area, results would likely differ from survey responses from a college town (Gallatin County) and a National Park gateway (Park County).

Integration to Current Understanding

Lentil production is perceived as a successful crop to include in rotation for the environmental, economic, and health benefits. The most valued reasons for including lentil in rotations were for (1) the rotational benefits from lentil, (2) price of lentil, and (3) nitrogen fixation. In order to become more widely adopted in production systems on the basis of rotational benefits, which may inadvertently promote sustainability within the food system, market demand and price need to be conducive for economic sustainability. In this study, producers reported adequate and consistent access to market and lentil distribution channels, though conventional producers reported effects from policy and market variability impact production. As such, producers identified the three most prevalent concerns regarding future lentil production that include (1) market demand and price of lentil, (2) weeds and pests, and (3) weather. Organic producers less prevalently reported impacts from drought, extreme weather, increased temperature, and pests and disease, however, impacts of weather variability on lentil production was experienced by most producers. A very low prevalence of producers reported they did not experience the effects of extreme weather on their agricultural business. This points to a need for climate adaptation strategies and policy measures put in place to support lentil producers.

The sustainability of lentil and other pulse in food systems have been highlighted by the UN declaration of the 2016 International Year of the Pulse, and include health benefits as well as supporting food security (Kissinger and Lexeme Consulting, 2016). Other studies have highlighted lentil and pulse for their respective health benefits, though few studies have been completed on human subjects. Messina (1999) highlighted the nutrient composition of legumes to support a healthful diet, including lentils, and the limited availability of epidemiological studies on the health effects of legumes on humans. Ganesan and Xu (2017) completed a review of health effects of polyphenols in lentils, and high dietary fiber and prebiotic content in relation to their role in prevention of non-communicable diseases such as diabetes, obesity, cancers, and cardiovascular diseases. Their findings highlight lentils contain slowly digestible starch that may maintain microbiota within the gut that could help to prevent diseases of the colon. Findings also highlighted lentils contain polyphenols rich in antioxidant potential that may protect against diabetes, obesity, cancers, and cardiovascular diseases.

Relatively few countries include pulse or promote sustainable foods in their dietary guidelines. In addition to the United States, countries that include pulse within national dietary guidelines are Australia, Brazil, Bulgaria, Canada, Greece, India, Ireland, Nordic countries (Denmark, Finland, Sweden, Iceland, Norway), Spain, South Africa, and the United Kingdom (Marinangeli et al., 2017). Marinangeli et al. (2017) completed a review to examine national dietary guidelines that include lentil and other pulse in order to unify a target adult serving size, and found 100 g of cooked lentils were a "reasonable" serving to contribute dietary nutrients, with claims such as high in fiber, iron, phosphorus, zinc, folate, and thiamin in the USA. The recommended adult serving of 100 g (per day) falls within suggested recommendations of eating for human health and planetary boundaries, which recommends

0–100 g of dried beans, lentils, and peas per day for a standardized 2,500 kcal diet (Willett et al., 2019). Willett et al. (2019) included considerations of planetary health when creating possible ranges of pulse serving size, similar to sustainability dimensions within select national dietary guidelines. The USA does not currently include sustainability within the dietary guidelines, though Mike Hamm, Timothy Griffin, and the Dietary Guideline Advisory Committee have placed considerable efforts to promote sustainability and sustainable foods within the dietary guidelines (Dietary Guidelines Advisory Committee, 2015). This points to an opportunity to promote lentils as a sustainable food source within future iterations of the Dietary Guidelines for Americans.

Lentil consumption in the USA is not part of the cultural history and is only a recently and sparsely adopted food source. In this study, consumption similarly remains low among informants. Portion size of lentils was not elucidated from the consumer survey, and the highest frequency of lentil consumption was "several times per week" reported by 12% of informants, while 28% of informants reported they eat lentils once a week. This leads to the conclusion that lentil consumption may remain below current dietary guidance of 100–300 g pulse per week per protein and vegetable food group, within this sample (United States Department of Health and Human Services and US Department of Agriculture, 2016). However, almost 60% of lentil consumers reported they increased their lentil consumption in the last 5 years, highlighting a trend in overall increased consumption. Producers can learn from consumers with respect to their purchasing habits and rationale for eating lentils. Likewise, consumers can learn from the production of lentil in relation to sustainability and make informed purchasing decisions.

Future Directions

Future directions with respect to lentil production include understanding and contrasting the different perceptions among producers in other lentil producing regions. Future research could integrate producer perceptions among conventional, organic, and mixed management systems in Idaho (USA), North Dakota (USA), Washington (USA), and Canada to understand the system more broadly and elucidate geographic and cultural differences. For example, results from the Palouse region in Idaho and Washington could highlight similarities and differences in management practices and perceptions from producers who have been producing lentil more historically. Representation from producers in Canada could highlight both similarities and differences and potential barriers and/or opportunities in future lentil production in similar landscapes across national borders.

With respect to consumers, results presented here indicate there are differences in knowledge of lentils between lentil consumers and non-consumers, and highlights opportunities for future research on social aspects surrounding lentil consumption, and educational outreach efforts to increase lentil consumption. Expanding on this research to understand perceptions among consumers in rural and urban areas would be important to highlight and contrast barriers and opportunities for lentil consumption among other demographics. It would be important to understand the perspectives among vulnerable populations in contrast to higher-income consumer groups, and among consumers with various levels of education. If barriers for lentil consumption are highlighted more broadly, targeted efforts can be placed to promote lentil consumption.

Due to the sustainability of lentil as a food system solution to promote environmental and human well-being, policy measures should be implemented that support lentil producers and consumers. For example, federal funds made available through the Farm Bill should be disbursed to incentivize best management practices producers already use, such as low-input, dryland, and diversified farms that include lentil. In addition, federal funds for research and development in value-added applications of lentil could enable an additional market demand for producers. Beyond canned soups and pre-packaged dahl, more recent lentil applications in value-added products include lentil flours which can be used in gluten-free baked goods such as cookies, crackers, chips, and breads and pasta (USA Dry Pea Lentil Council, 2016). In addition to incentivizing practices and supporting value-added applications of lentil, federal programs should support national food security and local farmers through the purchase of lentil to disburse in food programs such as Child and Adult Care Food Program, Federal Distribution Program on Indian Reservations, and the National School Lunch Program. Further, these federal food programs follow the advice from the Dietary Guidelines for Americans with respect to meals and menu-planning. Adding a sustainability dimension to future iterations of the Dietary Guidelines for Americans that promote increased consumption of plant-based protein and sustainable foods such as lentils, could create a platform for other areas of change. Bridging use of locally and/or nationally grown lentils within these food programs would create an additional market for producers while simultaneously supporting food security.

CONCLUSION

Lentil is food system solution that requires few inputs, contributes to the livelihood of regional producers, and provides a relatively low-cost high-quality plant-based protein source that supports multiple dimensions of sustainability through both production and consumption. As found by this study, management practices, market, and supporting plant-based diets are key components in the sustainability profile of lentil on the side of production. On the side of consumption, consumer willingness to increase lentil intake based on environmental, socio-economic, and nutrition information could be a key component to increase market demand.

Due to the recent and less developed culture of eating lentils in the USA, policy actions should support and incentivize lentil production and support increased consumption through national dietary guidance and through federal food programs that serve vulnerable populations. Utilizing lentils from local and/or national sources simultaneously supports multiple dimensions of sustainability while promoting food security.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board (IRB) at Montana State University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

TW, SA, CB, and PM contributed to the conception, design of the study, and wrote sections of the manuscript. TW performed the statistical analysis, created figures, and wrote the first draft of the manuscript. All authors contributed to manuscript revision and read and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2019.00088/full#supplementary-material

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