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The Last Mile: Using Local Knowledge to Identify Barriers to Sustainable Grain Legume Production

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Grain legumes (or *pulses*–annual leguminous crops that are harvested solely for their dried seeds such as lentils or chickpeas) are essential for sustainable cropping systems. They positively contribute to soil fertility and agricultural biodiversity and are a highly nutritious food source, yet they remain under-exploited across the world. In India–soon to be the world's most populous country and the world's largest importer, producer and consumer of pulses–they are substantially under-utilized and are the only major food group not to have increased in output since independence in 1947. Existing efforts to address low grain legume production have focused on the scientific and agronomic barriers, with little impact on productivity. In contrast, this project, using Tripura in India as a case study, recognizes the limits of imposing top-down solutions and instead focuses on the barriers to production as identified by the growers themselves. Working with 440 farmers from 19 non-tribal and 11 tribal villages in Tripura, NE India, we used facilitated discussion to identify their key barriers to pulse production, and facilitated pile sorting to identify the commonly consumed, grown and available pulses. Twenty-eight barriers to legume production were identified by farmers. The eight principal barriers were: insufficient water; lack of technical knowledge; unreliable seed supply; lack of processing units; soil fertility; financial constraints; limited fertilizer supply; and insufficient fencing material. These barriers are complex and overlapping and originate from system level failures to sufficiently prioritise grain legumes compared to cereals. However, recognizing the length of time it takes to address system level problems, in this paper we identify five immediately applicable mitigating strategies to help overcome the principle barriers identified here. Importantly, these will also create an improved environment to apply the technologically sophisticated grain legume R&D that has been carried out over the last 20 years but has yet to have a measurable impact on pulse production. Therefore understanding the wider socio-economic pathways to sustainable pulse production is essential to facilitate change on the ground. Our results, relevant to policy makers in India and around the world, demonstrate the value of listening

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to farmers when attempting to improve production, and emphasize the necessity of including the socio-economic systems surrounding pulse production, to complement the current emphasis on biological barriers.

Keywords: biological nitrogen fixation (BNF), participatory inquiry, indigenous technical knowledge (ITK), sustainable pulse production, pulse, India

INTRODUCTION

Grain legumes (or pulses -annual leguminous crops that are harvested solely for their dried seeds such as lentils or chickpeas) have a critical role in sustainable food systems (Franke et al., 2018): they are highly nutritious and they contribute positively to soil fertility and agricultural biodiversity (Crews and Peoples, 2004). Yet these properties are often underappreciated on the ground, with key agricultural policies focusing on cereals at the expense of grain legumes (Pingali, 2015). In India, soon to the be the world's most populous country and the world's largest importer, producer and consumer of grain legumes, pulses remain the only major food group not to have increased in output since independence in 1947 (Varadharajan et al., 2013).

Existing research effort has focused on the biological barriers to pulse production, including: genetic enhancement (yield and grain quality) (Cowling, 2015); tolerance to biotic and abiotic stresses; development of integrated pest and disease management (Varshney, 2016); and the sequencing of rhizobia (Rai et al., 2017). In addition there is work on sustainable farming approaches (such as intercropping and crop diversification) using legumes to improve nutrient management and productivity (Choudhary et al., 2014; Dwivedi et al., 2015; Shukla et al., 2017). These agronomic approaches are providing effective solutions to the barriers identified by experts, but critically they have yet to lead to an increase in production. With this research effort, why is production still limited?

In this paper we take a new approach to the seemingly intractable problem of insufficient grain legume production in India. Unlike other work, which has focused on expert determined agronomic constraints (see Ghosh et al., 2007), this paper draws on the farmer's lived experience to gain their understanding of the barriers to production.

As far as we know, there has been no work on the local knowledge and underlying farmer perception and awareness that drives local decision-making for legume production in India. In this paper we asked indigenous farmers why, despite the beneficial qualities identified here, production remains limited, and propose five immediately applicable solutions to begin to overcome the systemic barriers to underutilization of pulses.

BACKGROUND

Chronic malnutrition remains endemic throughout India. 38.4% of under-5 s are stunted, condemning these children to less schooling (Adair et al., 2013; Byerly, 2016), lower earning potential (Hoddinott et al., 2013), increased morbidity and lower cognitive function in adulthood (Onis and Branca, 2016; Akombi et al., 2017). Adult malnutrition metrics remain stubbornly high too, and increasingly include the double burden of malnutrition: approximately a fifth of adults remain underweight and the same proportion have become obese in 2015–16, substantially more than 10 years previously (**Table 1**).

The roots of malnutrition include complex socio-political drivers, but the proximal physiological drivers are disease—determining the demand and uptake of nutrients—and nutrition—which and how many nutrients are consumed. When sufficient pulses are eaten in conjunction with cereals (such as rice or wheat) the subsequent meal provides a full complement of essential amino acids, as pulses are a good source of the cereal-limited amino acid lysine (Kurpad and Minocha, 2017). However, while pulses are typically the most economical choice of protein, and protein deficiency remains a major challenge both in terms of quantity and quality, intake of pulses remains low, especially in rural areas with 80% of the population failing to reach their RDA intakes (Vecchio et al., 2014). Milk and other dairy products, which provide a full component of critical amino acids, have substantially increased in production following the white revolution of *Operation Flood,* and contribute 10 and 12% of protein intake in rural and urban Indian diets respectively. However, dairy products remain relatively expensive, so that access is restricted to higher socio-economic groups (Kurpad and Minocha, 2017).

In addition, pulses are high in fiber and minerals (particularly potassium, phosphorus, calcium, copper, iron, and zinc), whole-grain legume consumption has been suggested to reduce heart disease, stroke, and to increase longevity (Kushi et al., 1999; Darmadi-Blackberry et al., 2004; Flight and Clifton, 2006).

Nitrogen is the most limiting nutrient in agricultural soils worldwide. Through associations with rhizobial bacterial communities in root nodules, pulses have the potential to biologically fix nitrogen. The bacteria convert inert atmospheric nitrogen into plant available nitrogen, displacing the need for economically and environmentally expensive synthetic nitrogen (Das and Ghosh, 2012). However, it should be stressed that pulses are not a simple remedy for nitrogen limited soils. Some soils do not contain appropriate rhizobial communities, resulting in poor nodulation by ineffective rhizobia (Vanlauwe and Giller, 2006). Effective N fixation is further limited in the water stressed conditions used for much pulse production in India, not because rhizobium communities cannot survive, but because growth and movement of rhizobia is decreased thus limiting symbiotic establishment (Leung et al., 1994).

In addition to fixing nitrogen, pulses also increase soil organic carbon and phosphate availability (Stagnari et al., 2017), both of which are important in maintaining or improving soil quality. Legume supported agriculture, where legumes are grown with other crops, has the potential to reduce artificial

TABLE 1 | Nutritional status of adults in India showing trends in malnutrition including a decrease in underweight adults and an increase in overweight adults of both genders from 2005–6 to 2015–16 http://rchiips.org/NFHS/pdf/NFHS4/India.pdf.

Indicators	NFHS-4 (2015–16)			NFHS-3 (2005–06)
Nutritional status of adults (age 15–49 years)	**Urban (%)**	**Rural (%)**	**Total (%)**	**Total (%)**
Women whose Body Mass Index (BMI) is below normal (BMI < 18.5 kg/m^2) (%)	15.5	26.7	22.9	35.5
Men whose Body Mass Index (BMI) is below normal (BMI < 18.5 kg/m^2) (%)	15.4	23.0	20.2	34.2
Women who are overweight or obese (BMI $\geq$ 25.0 kg/m^2) (%)	31.3	15.0	20.7	12.6
Men who are overweight or obese (BMI $\geq$ 25.0 kg/m^2) (%)	26.6	14.3	18.9	9.3

nitrogen requirements and maintain yields without overloading the system with reactive nitrogen.

Although pulses have a key role for nutrition and in maintaining and improving soil fertility, which is in turn important for yields and livelihoods, India's outputs of pulses has remained stubbornly low. Legume production in India has not kept pace with other crops; total production has changed little in the past 50 years and there is a significant yield gap compared to other countries. India's pulse yields remain at 0.5–0.7 tons/hectare while other countries, such as Canada and Myanmar, have achieved yields of 1.3–2 tons/hectare (Minocha et al., 2017). One reason for this stagnation in yield compared to other countries and other crops in India is the change in where pulses are grown. From the 1960s to 2000s the area down to pulses in India has remained approximately constant (a 3% decline) but the location of production has radically shifted: while pulses were once part of the rotation in most areas of India—including those with more fertile soils—the high guaranteed prices for rice and wheat (incentivised to avoid the mass starvation such as the Bengal Famine of 1942–1943, which provided the backdrop to India's Independence) have pushed pulses to marginal, rainfed areas (Martorell et al., 2009). Growing in rainfed areas without irrigation leaves farmers vulnerable to erratic rainfall, in some seasons resulting in localized harvest failure. Importantly, the increased production of other high quality sources of protein such as milk and chicken are high value and generally exported from rural areas to be consumed by the relatively affluent (Byerly, 2016), so that pulses remain the most important source of high quality protein for the poor. In 1998 India imported 9% of the total world pulse trade, and it's share increased to as much as 50% in 2016[1] and India needs to import 25% of its legume requirements (Kurpad and Minocha, 2017).

Where the potential role of pulses has been appreciated, many attempts to resolve the low output and low yields have focused on scientific or technological advance. While technology can address the practical challenges to production, a top-down approach that focuses on agronomy may miss key barriers that limit the ability of farmers to implement the advances in technology. In this paper we focus on the lived—experience, using a case-study approach to collate local knowledge on the role of legumes in the local food system with opportunities and barriers for increased legume production set within a framework of the role legumes play in local diets, the role of legumes in soil fertility and the current extent of cultivation.

Here we present data from tribal and non-tribal communities separately. The value of particular foods varies with cultural context (Rozin, 1996) as does agronomic technique (Maikhuri and Ramakrishnan, 1990); evidence confirms that these patterns are repeated in Tripura (Deb et al., 2013) yet the differences are poorly explored. Our approach will enable us to identify socio-economic barriers in addition to agronomic barriers, for example whether policy needs to be adapted accordingly in order to support the farmer uptake of legume production. To gather the information we used structured discussions to gather local knowledge followed by the social science approach of "pile sorting" (Gollin et al., 2004). Recognizing the importance of interdisciplinary learning to enable us to fully understand the system under investigation and the value of taking an integrated approach to legume production, this will lead to a new and more complete understanding than is currently available. This paper complements others which have focussed on agronomic aspects (Ghosh et al., 2007).

MATERIALS AND METHODS

The study was conducted in the East Indian state of Tripura in June, 2016. Tripura is administratively divided into eight districts, and the study sites were located in the district of West Tripura. West Tripura also contains the state capital Agartarla, and is bordered by Bangladesh in the North and West and by the Khowai and Sipaijala districts of Tripura in the East and South. The total area of the district is 942.55 sq km with a population of 988,192 (census 2011). The majority of the population is dependent on farming and 40% of the district's land is under agriculture[2]. There are a number of indigenous ethnic communities in Tripura which are referred to as Tribes; the Tribes are represented by the Tripura Tribal Autonomous District Council (TTADC).

[1] http://ipga.co.in/pulses-trade-flow-to-indian-subcontinent (Accessed November 16, 2016).

[2] http://www.tripurainfo.com (Accessed June 10, 2018).

The West Tripura district includes both tribal and non-tribal communities, and contains 30 Gram Panchayats (GP) (rural constituencies), the smallest effective administrative block in the state. A total of 30 GPs were selected for this study, each comprising several villages. Farmer participants were drawn from villages across all GPs.

To collate local knowledge, farmers from 19 non-tribal GPs and 11 tribal GPs were invited to take part in focus groups. Surveys were conducted in each GP separately on different days. On behalf of the research team, a Village Level Worker ("VLW") from the state Agricultural Department communicated with the "Pradhan" (Head) of each GP, and the farmers, prior to the survey. The Pradhan plays an important role in village life; he is a democratically elected representative of the community and great trust is placed in his judgment. No survey work can take place in rural villages without his support. The VLW and the Pradhan discussed the research goal, before mutually determining the practicalities of carrying out the survey. Most of the surveys were conducted in a farmer's home where participants felt relaxed. In each GP farmers formed three focus groups of between three and seven famers (14.67 ± 0.30 farmers from each Gram Panchayat) depending on the number of participants. Groups were split by gender to facilitate the full participation of all members. With the exception of gender, participation in groups was allocated randomly. Focus groups were separated so that there was no interaction between groups. This process was carried out in two stages.

Stage 1: Structured Discussion in Focus Groups

Engagement: some questions were included to engage farmers in the discussion, to help them relax into the discussion. For example, participants were asked to name the meals they prepared with legumes and to share details of all the ingredients they used in those meals. The farmers generally enjoyed sharing recipes and visibly relaxed after this question.

A set of semi-structured questions was then asked of the group in a facilitated discussion (Martin, 1995) (**Table 2**) with the aim of:

1) Knowledge gathering: gathering perceived facts about legumes, their nutritional value and their relationship to soil fertility.
2) Substantiation: to enable researchers to understand the route by which knowledge was acquired.

There was discussion within each group, recorded by dictaphone, and all participant final decisions were reached by consensus. The discussion was facilitated but the facilitator was careful not to influence the responses. Keywords from the responses were coded for analysis. The barriers were then identified by grouping the responses using keywords.

Stage 2. Participant Perception of the Rank Importance of Legumes: Frequency of Consumption, Availability, Nutrient Content, and Overall Performance

A pile sorting exercise was carried out (Martin, 1995). Pile-sorting is a qualitative method which uses objects to enable the participants to identify items that exist within a cultural domain. Different pulses were placed into transparent plastic bags and laid out before participants (**Table 3**). In the first instance the group was asked to identify which legumes they recognized. Unrecognized legumes were removed from the exercise. Participants were then asked to arrange the legumes in rank order according to:

1. The most frequently eaten
2. Most easily available
3. Most nutritious

TABLE 2 | Questions used in semi-structured discussions within focus groups.

Question	Purpose
1. Describe the cropping calendar for legumes	Knowledge gathering
2. Name the dishes you prepare with legumes or pulses?	Knowledge gathering Engagement
3. Which legumes or pulses are in those dishes?	Knowledge gathering Engagement
4. Which are your favorite dishes?	Engagement
5. Which dishes are the most nutritious—legume based, other vegetable based or meat based dishes	Evidence gathering
6. How do you assess this?	Substantiation
7. What is the status of current soil fertility on the local farms?	Knowledge gathering
8. How do you assess soil fertility status?	Substantiation
9. Has soil fertility changed in recent years?	Knowledge gathering
10. If you think that soil fertility has changed, how do you assess this?	Substantiation
11. Are there any traditional methods that are commonly used to increase soil fertility? What are they?	Knowledge gathering
12. How do these methods help to increase soil fertility?	Knowledge gathering Substantiation
13. How do you assess this?	Substantiation
14. Are you using traditional methods or/and modern methods?	Knowledge gathering
15. What are the modern methods and how do they increase soil fertility?	Knowledge gathering
16. How do you assess this?	Substantiation
17. Do you think there is any relationship between growing legumes and soil fertility?	Knowledge gathering
19. If you think there is one, how did you arrive at this conclusion?	Substantiation
20. Are there any specific legumes that are particularly good for soil fertility?	Knowledge gathering
21. How do you know they are good for soil fertility?	Substantiation
22. Why don't you grow more legumes?	Knowledge gathering
23. What factors limits legume yield?	Knowledge gathering
24. How do you know these factors are responsible for limiting legume yield?	Substantiation

Each question had one of the purposes: to gather knowledge; to engage and encourage the participants in discussion; to substantiate the source of their knowledge.

TABLE 3 | Names and 2017 local market prices of 15 legumes used in a pile sorting exercise with participant farmers.

Common English name	Bengali name	Scientific name	2017 Market Price (Rs./kg)
Beans	Beans	*Phaseolus* spp.	40
Bengal gram	Chola	*Cicer arietinum* subsp	80
Black gram	Maskalai	*Vigna mungo*	100
Cowpea	Borboti	*Vigna sinensis*	30
Chickpeas	Kabuli chola	*Cicer arietinum* subsp	180
Broad beans	Sim	*Vicia faba*	40
Green pea	Motor	*Pisum sativum*	80
Green gram	Mung dal	*Vigna radiata*	100
Kidney beans	Rajma	*Phaseolus vulgaris*	100
Grass pea	Kheshari dal	*Lathyrus sativus*	50
Pigeon pea	Arhor dal	*Cajanus cajan*	100
Red lentil	Musur dal	*Lens culinaris*	85
Soya beans	Soya bean	*Glycine max*	80

4. Which was considered "best" all round i.e., that performs well in terms of profitability, nutrition and providing soil fertility.

Each group performed this activity separately. There was discussion within each group about the selected rankings and the order was reached by consensus. The discussion was facilitated but the facilitator was careful not to influence the rankings.

Ethical Framework

At the outset a consent letter describing the objectives of the survey, the intended outputs, the name of the national and international collaborators, boundary partners and funding body was read out by a member of the research team to the farmer participants. The consent letter was then distributed among the farmers in the local language. If the farmers agreed to take part in the process they signed the consent letter, those who wished to withdraw then had an opportunity to do so. No payment was made for taking part and no pressure was applied to ensure people did so.

RESULTS

A total of 57 non-tribal groups and 32 tribal groups comprising 440 farmers participated in the survey. Among those 440 farmers, 168 farmers were from 11 tribal Gram Panchayats (GP; rural constituencies) and 272 farmers were from 19 non-tribal GP. There was a greater number of male participants (352 farmers) than female (88 farmers). This disparity is accounted for by low participation of women farmers from non-tribal areas. The female to male participant ratio was quite high in the tribal areas (0.45) when compared with non-tribal areas (0.15). The majority of the participants were between 26 and 45 years (216 farmers, 49.09%), with remaining were mostly between 46 and 60 years (155 farmers, 35.23%). Few participants were either older (>60 years: 44 farmers, 10%) or younger (19 to 25 years 24 farmers, 5.45%). There was some variation in the education level of farmers. 35.91% were educated up to the age of 10 (0–5th standards, 158 farmers), 34.09% were educated up to 16 (between 9 and 10th standards, 150 farmers).

Barriers to Production—Outcome of Focus Groups

A total of 15 legumes were grown on local farms (**Table 3**). However, despite identifying these as locally cultivated, farmers indicated that actual production was very low. Farmers tried to grow legumes throughout the year in both tribal and non-tribal villages, irrespective of best practice. High variation in the cropping calendar between different villages, as well as within a single village, was observed (**Electronic Supplementary Material**). Seed was unavailable on the open market and the farmers relied on seed supply via government and NGOs, and the quality, the quantity and the timing of availability was highly variable. Farmers stated that seed was often distributed outside the optimum cropping window for legume growing and that the timing of the distribution was unpredictable. This led to large variation between farmers in when legumes were grown and was a major influence on the success or failure of the crop. Farmers also acknowledged that their own lack of knowledge of the optimum cropping windows of different legume species contributed to the variation in the cropping calendars. A further complication was the overlap in cropping windows of legume crops with more profitable cash crops such as rice and brinjal (egg plant/aubergine) which are prioritized by farmers, who then attempt to grow legumes off-season. Consequently, early or late sowing and harvesting of legumes is common when grown in rotation with economically important crops.

Limits to Cultivation

Farmer participants identified 28 barriers to legume cultivation (**Figure 1**). Some barriers were identified by only a single or small number of the 89 groups. In order to prioritize barriers we have focused on those identified by five or more of the groups. These were: limited access to water; limited seed supply; poor soil; lack of technical knowledge to support cultivation; financial

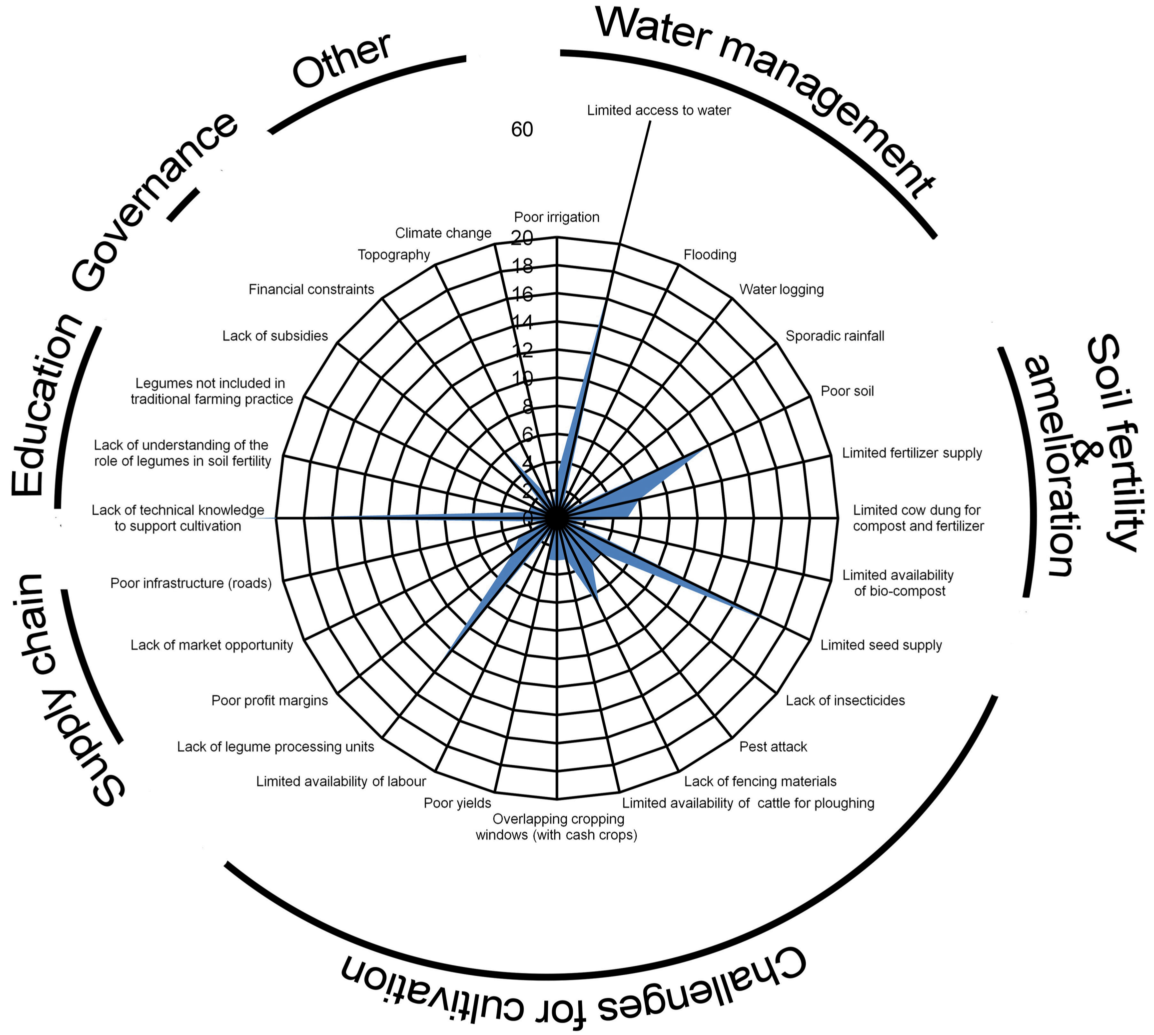

FIGURE 1 | Barriers to grain legume production as identified by farmers. The Y axis indicates the number of farmer groups that identified each Barrier.

constraints; lack of legume processing units and fencing materials (**Figure 1**).

Participant Assessment of Changes in Soil Fertility

The majority of farmers reported that soil fertility was decreasing (non-tribal 98.25%, tribal 96.88%). This was based on their perception although there was no long-term scientific data to support this. Decrease in crop yield, increasing fertilizer application and change in soil texture along the years were the three main criterion farmers used to judge soil fertility. Concomitantly, a small number (non-tribal 1.75%, tribal 3.13%) reported an increase in soil fertility and these farmers cited the addition of chemical fertilizers as the principle driver for this. However, there was some disagreement; other groups reported that chemical fertilizer drives low soil quality as it "makes the soil hard" which in turns decreases soil fertility. Poor soil fertility was also attributed to the lack of available cow dung; traditionally cow dung was used to make the soil "soft" which was considered by farmers to be one indicator of soil fertility.

TABLE 4 | Farmer assessment of the percentage change (reduction) of soil fertility in recent years.

	1–20%	21–40%	41–60%	61–80%	Not answered
Tribal (%)	0	19.30	49.12	15.79	14.04
Non-tribal (%)	0	3.13	53.13	15.63	28.13

Farmers also attempted to quantify the decrease in soil fertility using percentages. The minimum given was 20% with a maximum within a bracket of 41–61% (**Table 4**). Farmers used the reduction in yield (non-tribal 51.85%, tribal 38.89%,) and the increase in fertilizer use as (non-tribal 37.04%, tribal 44.4%) and as the principle criteria to assess soil fertility loss.

TABLE 5 | Farmer assessment of traditional practices to increase soil fertility (farmer-identified).

	Cow dung compost	Leaf compost	Ash	Plowing with traditional tools	Jhum cultivation	Organic compost	House compost	Mechanical weed removal (Trad.)	Increase earthworm in soil	Mustard cake
Tribal (%)	90.63	34.38	6.25	6.25	6.25	0.00	0.00	0.00	0.00	0.00
Non-tribal (%)	100	22.81	33.33	7.02	3.51	3.51	3.51	1.75	1.75	1.75

As each group was able to give multiple answers, the percentage may exceed 100%. NB. Jhum cultivation is slash and burn agriculture.

TABLE 6 | Farmer assessment of new practices to increase soil fertility (farmer-identified).

	Chemical fertilizer	Vermicompost	Organic compost	Bio fertilizer	Poultry manure	Mustard cake	Lime	Legume cultivation
Tribal (%)	65.63	31.25	18.75	3.13	3.13	0.00	0.00	0.00
Non-tribal (%)	49.12	22.81	49.12	5.26	1.75	1.75	1.75	1.75

As each group was able to give multiple answers, the percentage may exceed 100%.

Traditional and New Practices Aimed at Increasing Soil Fertility

Both tribal and non-tribal farming groups identified 10 traditional practices (**Table 5**) and eight new practices (**Table 6**) which that they considered increased soil fertility. Among the traditional practices both tribal and non-tribal groups identified cow dung compost, leaf compost and ash as the three most important (**Table 5**). Of the new techniques, chemical fertilizer, vermicompost, and organic compost were the top three new techniques identified by the tribal and non-tribal farming groups to increase soil fertility (**Table 6**). Legume cultivation for soil fertility was mentioned under "new" techniques but was suggested by very few farmers, all who were non-tribal. However, despite knowing about diverse ways to ameliorate poor soil, farmers restricted their practice to chemical fertilizers and cow dung applications (**Table 7**).

TABLE 7 | Techniques to improve soil fertility currently implemented by the participants on their farms.

	Cow dung compost + Chemical fertilizer	Chemical fertilizer	Cow dung compost
Tribal (%)	94.74	5.26	0
Non-tribal (%)	71.88	21.88	6.25

TABLE 8 | Farmer assessment of the impact of legumes on soil fertility.

	Increased fertility	Decreased fertility	Uncertain
Tribal (%)	56.25	31.25	12.5
Non-tribal (%)	89.47	10.53	0.00

The Role of Legumes in Soil Fertility

There were contrasting perceptions among the various focus groups on the role of legumes in soil fertility. Tribal farmers were less certain than non-tribal farmers and 12.5% of tribal groups indicated that they didn't know whether legumes affected soil fertility or not. However, the majority of farmers indicated that they thought that legume cultivation can have a positive impact (**Table 8**). There were also some groups that considered that the opposite was true and that legumes had a negative impact on soil fertility and this was particularly true of tribal groups. While the majority of farming groups recognized the positive soil fertility impact of pulses, few (non-tribal 49.12%, tribal 21.88%) were aware nodule formation and "N_2" fixation by leguminous plants.

Most groups from both farming communities recognized that soil organic matter is an important criterion for a fertile "good" field (tribal 65% and non-tribal 90.63%) and that the absence of organic matter in the soil indicates a "bad" field (tribal 35% and non-tribal 75%). However, a few of the farming groups from both the farming communities also stated that sometimes organic matter present in the soil does not imply that it is a good field (non-tribal 15.63%). Sometimes good fields were considered to have a low soil organic component (tribal 20% and non-tribal 3.13%). Fifteen percent of tribal groups and 6.25% of non-tribal groups did not support the link between soil organic matter and soil quality in wither good fields or bad fields (tribal 35% and non-tribal 9.38%).

Stage 2

Frequently Eaten and Easily Available Legumes

Participants from both non-tribal and tribal communities said that they most frequently ate those legumes which were easily available in the local market. This is demonstrated in **Tables 9**, **10**. In conversation, farmers revealed that they also valued the flavor of particular legumes irrespective of their availability and nutritional quality. Nutritional quality was typically judged by how easily a foodstuff was digested, although the farmers also relied on information from books and information provided by doctors. For example in non-tribal areas green gram is the second most consumed whole legume yet it is not easily available (**Table 9**) (soy was recognized as a legume by farmers, but it was consumed as textured vegetable protein, and as this project is interested in production barriers, while including it in the raw

TABLE 9 | Farmer assessment of the frequently consumed and available pulses in non-tribal villages.

	Red lentil	Soyabean	Green gram	Field bean	Cowpea	Bengal gram	Black gram	Lathyrus sativus	Green pea
Frequently eaten	100	70	53.33	36.67	23.33	10	3.33	3.33	0.00
Easily available	81.48	3.33	40.74	22.22	25.93	3.70	18.52	11.11	3.70

The table shows legumes that were ranked in the top three in a pile sorting exercise. As groups were able to choose equal ranking for a legume, the percentages can total more than 100%. Soyabean is recognized by farmers as a pulse, but is only locally available as textured vegetable protein, and so can be ignored from the core questions in this research project.

TABLE 10 | Farmer assessment of the frequently consumed and available pulses in tribal villages.

	Red lentil	Cowpea	Soyabean	Field bean	Pea	Bean	Green pea	Bengal gram	Pigeon pea	Bengal gram (processed)
Frequently eaten	100	85.71	64.29	28.57	14.29	0.00	0.00	0.00	0.00	0.00
Easily available	85.71	78.57	64.29	14.29	7.14	14.29	14.29	7.14	7.14	7.14

The table shows legumes that were ranked in the top three in a pile sorting exercise. As groups were able to choose equal ranking for a legume, the percentages can total more than 100%. Soyabean is recognized by farmers as a pulse, but is only locally available as textured vegetable protein, and so can be ignored from the core questions in this research project.

data, we are excluding it from discussion). In tribal areas several available legumes were not eaten at all (**Table 10**), even though they are considered nutritious because they were not traditionally eaten. Bengal gram for example, is considered nutritious but is not frequently consumed.

DISCUSSION

West Tripuran agriculture, in keeping with low and middle income country (LMIC) farming systems around the world, produces food for both the kitchen and the market. This form of partial subsistence agriculture provides an important framing to the concern of pulse production barriers, as improved pulse production has the potential to directly improve family nutrition, as well as broader household livelihood concerns. The farmer focus groups identified 22 barriers to pulse production ranging from limited availability of seed to limited availability of cattle for plowing (see **Figure 1**). Of these, eight barriers were identified by over 5 of the groups. These are discussed individually below, but should be seen as part of a wider pulse food system, as depicted in **Figure 2**. In the light of this discussion we identify five mitigating strategies to overcome the barriers identified here. Importantly, these will also create a fertile environment for the application of more technologically sophisticated R&D that has been carried out over the last 20 years but has yet to have a measurable impact on pulse production.

1. Limits to water
   Almost two thirds (63%) of farmer focus groups identified limited access to water as the key barrier to pulse production. However, there is a paradox in addressing this barrier, as at most sites it is not that water limits pulse production, but that pulses are only grown on water-limited land; where irrigation is available, the land is used is used for crops with a ready market such as rice. This is a pattern across the whole of India–pulses have been marginalized from the fertile and irrigated areas since India prioritized wheat and rice in its drive for self-sufficiency in the 1960s (Bhadana et al., 2013). In West Tripura pulses are grown in the dry season, but the majority of irrigable land (19.77% of gross cropped area) is planted to rice in this season rather than pulses due to its ready market (Tripura, 2001).
   Therefore, if the options farmers most often call for (large infrastructure schemes such as dams or canals, or subsidized tube wells) were implemented, this could result in reduced pulse production, as marginal pulse-producing land is converted to irrigated rice. The problem of insufficient water supply is in large part a problem of the agricultural commodity market in India which is largely dictated by the state (Pingali, 2015): farmers are economically rational in the short term by planting rice where irrigation allows, at the long term cost to soil quality, climate and biodiversity.
   Until the wider market drivers are adjusted to include the positive nutritional and environmental externalities of pulse production, we suggest that focusing irrigation effort at the farmer scale will be most effective at increasing pulse production—in addition to avoiding the economic, social and environmental costs associated with large scale irrigation schemes. Farmer scale options to address limited water supply can be addressed through increasing the available water, or reducing water demand—both strongly interacting with other barriers identified by the farmers, and heavily depending on technical knowledge. Available water can be increased through changing tillage options, improving the timeliness of sowing, building check dams or increasing the soil organic carbon content (addressing poor soil) (Hatfield et al., 2001; Agoramoorthy et al., 2008). Reducing water demand can be achieved through optimizing nutrient availability—too much nitrogen can result in excessive growth and over-use of water before flowering (Passioura, 2006), irrigation methods and crop choices. Different pulse species have different abilities to adapt to drought, for example red lentil [the most frequently consumed pulse (**Tables 9**, **10**)], and pigeon pea have substantially lower yield losses in drought situations compared to black gram or green gram (Daryanto et al., 2015).
2. Lack of technical knowledge to support cultivation
   Twenty-two groups self-identified their own lack of technical knowledge as a barrier to pulse production, echoing

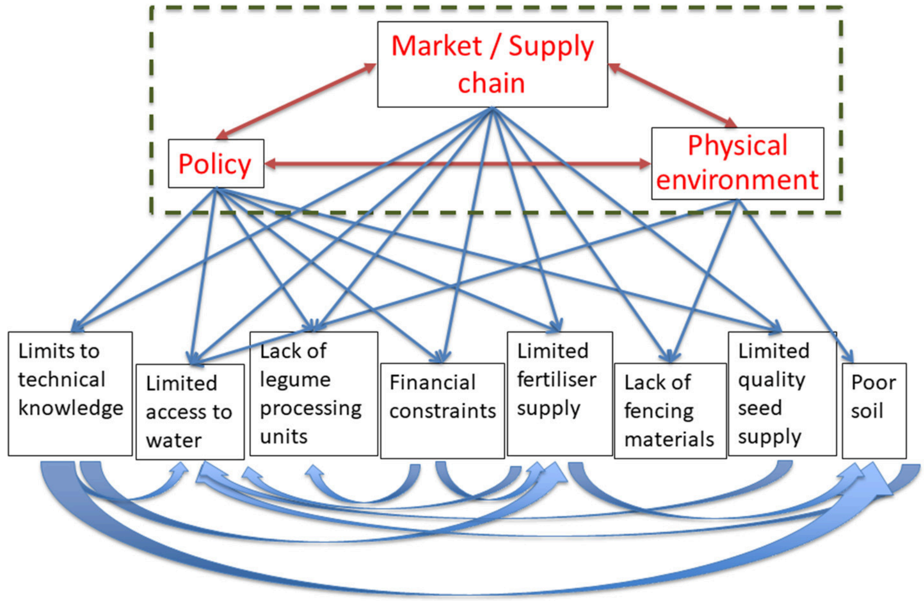

FIGURE 2 | The integrated barriers to pulse production. The key barriers (the eight boxes at the base of the figure) all derive from one or more aspects of the wider food system–in this figure is divided into: Market/supply chain; Physical Environment; and Policy. The links from the core system to the barriers are demonstrated using straight arrows. The barriers also have multiple interacting elements themselves, identified through the curved arrows at the base of the figure. For example, overcoming technical knowledge gaps can help address limited access to water through changing agronomic practices such as plowing and planting date; it is important for soil fertility through guiding methods to increase soil structure; and to limited fertilizer supply through guiding farmers about the appropriate fertilizers required, and the N fixing potential of pulses. These interactions are described in the text. Overall the results demonstrate the importance of looking at the system as a whole—addressing just one aspect will not successfully generate an increase in appropriate pulse production.

the knowledge gap identified as a key barrier to pulse production in developed-world agriculture (Zimmer et al., 2016). Addressing knowledge gaps in disenfranchised groups is complicated by a long history of marginalizing all indigenous and traditional knowledge from policy and research arenas (Sutherland et al., 2013; Smith et al., 2017). It is therefore important to work with farmers in identifying and solving specific knowledge gaps, rather than imposing new production systems that ignore existing know-how. Pulse cropping is not widely practiced in Tripura, and for some farmers pulses are a new crop. Many farmers revealed fundamental knowledge gaps, for example reporting confused cropping calendars, and believing that pulses offer no benefit or reduce soil fertility. However, addressing the barrier of limited technical knowledge–which underpins several of the other barriers (see **Figure 2**)–is not a panacea; it is important to recognize that the behavior change needed to achieve increased sustainable pulse production requires changes in perceptions and attitudes as well as knowledge (Meijer et al., 2015). For example, farmers at present have little incentive to address the knowledge gaps related to pulse production as pulses remain a crop with a marginal market, and existing attempts to grow it have resulted in problems due to lack of processing, poor water supply and the other barriers identified here. This is a complicated chicken and egg problem. Farmers can't grow pulses effectively without knowledge, but won't gain the knowledge without confidence of a market, and the market won't exist until there is a clear supply. Structural intervention is required to solve this problem.

In addition, even when there is a clear demand for new knowledge, effectively disseminating knowledge is a complex process; methods of knowledge dissemination are key to its effectiveness (see for example Stoop et al., 2009). Globally, extension services are often inadequately trained in both the core areas of knowledge they need to disseminate, or the skills they need to effectively communicate that knowledge. This research has shown that there is substantial room for improvement within existing efforts to disseminate knowledge in West Tripura.

3. Limited seed supply

The provision of high quality seeds can provide substantial yield benefits; an improved chickpea variety delivered 15–20% increase in productivity, a greater gain than addressing either lack of expertise or poor seed storage (Shekhawat, 2013). In addition to seed quality, the timing of seed provision is critical to allow optimal planting–especially when growing in the dry season and on un-irrigated land–to maximize available water.

In this study inadequate seed supply, including quantity, quality, timing and reliability, was identified by 18 farmer groups as a barrier to pulse production. It is unclear why the private sector does not provide high quality pulse seeds. It is technologically simple and other vegetable seeds were widely available and there are already 550 high yielding, disease resistant, pulse varieties, developed for different agro-ecological zones in India (Bhadana et al., 2013). This suggests that the limited seed supply is a deficient market rather than a seed breeding problem. The lack of provision is likely due to real or perceived farmers unwillingness to invest in high quality seeds when they are unsure of good yields, further exacerbated by the lack of market, processing units and other barriers identified here. This lack of available, high quality pulse seed in marginal agricultural areas has been noted elsewhere (Bhadana et al., 2013).

In Tripura, government and NGOs attempt to compensate for inadequate market provision of legume seeds. However, in our study it was clear that the government distributed seed was of poor quality and the timing was unpredictable. The unpredictable delivery of seeds exacerbated the problems caused by low seed quality as farmers typically planted on receipt of seeds, giving poor results. This is linked to inadequate storage facilities and a low knowledge base among the farmers; evidenced by the unaligned cropping calendars (**Electronic Supplementary Material**).

In addition to sub-optimal governance, infrastructure is also likely to hinder seed provision as the landlocked north eastern states, of which Tripura is one, rely on circuitous road transport from "mainland" India, resulting in delays and potential spoilage. However, it is significant that provision from government sources typically arises via the tender process, which suggests that there could be improved standards and controls for accepted tenders to manage both quality and delivery of seeds.

While the provision of high quality, virus free seeds, ideally coated with appropriate strains of rhizobia, is clearly the optimal option, until these are reliably available the improved storage of seeds on farm could be a useful option for farmers. With relatively little training this can be done cheaply and effectively with appropriate vessels, and while there is no local advantage to seed storage due to the absence of local land races, the advantages of reliable supply and autonomy to farmers suggests that this could be a practical and immediate solution. Engaging farmers in participatory technology and variety development together with the development of a market for high quality affordable seeds, are important if the results are to be delivered on the ground (Bhadana et al., 2013).

4. Lack of legume processing units

Post harvest, most pulses are milled before consumption. The process is important for both adding value to pulses grown, and also for the preparation of pulses for home consumption. However, there is a poor network of mills in Tripura and farmers cited the difficulties of milling their produce as a constraint. Existing mills are patchily distributed in urban areas, making access both impractical and expensive for farmers. This has been recognized as problem in other areas and an increase in access to mills has been highlighted as important in developing agro-based industries to support rural livelihoods (Paramasivan and Pasupathi, 2016). Other authors have identified infrastructural constraints including adequate warehousing for safe storage and a lack of suitable threshing floors (Singh et al., 2015) but there is little evidence that this is being addressed. As capital investment generally increases in-line with market opportunity, the introduction of mills must be aligned with the developments of markets for pulses in Tripura (Paramasivan and Pasupathi, 2016).

5. Poor soil

Twelve groups of farmers identified poor soil as a significant problem for grain legume production and perceived that soil quality was declining (**Table 4**), unsurprising when most of the more fertile soils are used for wheat/rice production, and many of the soils in the region are acidic and deficient in micro-nutrients (Singh et al., 2015). Farmers identified soil fertility decline using crop yield and the amount of fertilizer they needed to apply although in the <5% of cases where farmers considered that soil fertility was increasing, they linked it to the use of fertilizers. While chemical fertilizers were not always considered "good" (they were sometimes associated with "hard soil" unlike cow dung which was said to make the soil "soft") they were identified as a potential solution to their poor soil. As discussed under "limited fertilizer below," targeted fertilizer is important to achieve high pulse yields–especially phosphorous for effective biological fixation of nitrogen (BNF).

Both the traditional and new practices identified by the farmers to increase soil fertility (**Tables 5**, **6**) are practices that increase soil organic carbon, an option that could mitigate inadequate water supply. However, very few of these practices are implemented—while farmers identified 18 potential ameliorative measures for fertility, they only used three on their own farms (chemical fertilizers, cow dung and a combination of the two). The reliance upon such a small range of options was due to a perceived lack of available feedstocks. It is possible that increased yields could provide additional biomass, and alternative technologies-such as biochar rather than biomass stoves-could provide new options for increasing the efficiency of existing biomass use.

6. Financial constraints

Financial constraints, whether they result from insufficient capital, income or access to affordable loans, typically result in a low risk approach to agriculture (Cole et al., 2016). These constraints are also likely to limit investment, especially for a less familiar crop with a less secure market, such as pulses. The impact of the other identified barriers such as poor seed quality or lack of legume processing units further reinforce the financial constraints. Overcoming farmer financial constraints to pulse production is integral to the establishment of an effective pulse production system. There are numerous potential methods for overcoming financial constraints in isolation, for example through direct subsidies or loans to farmers, or through the establishment of guaranteed markets (for example changing the tender' criteria for pulses used in the Midday Meal Scheme—India's nation-wide school meals system—to ensure purchase of local pulses), or through the establishment of local processing centers. Although the cultivation costs for legumes are relatively low, the high minimum support price (MSP) for cereals, and their higher yields relative to legumes, skews farmer choice toward cereals. Finally, addressing the pulse yield gap also has a key role in reducing financial constraints for farmers (Kurpad and Minocha, 2017).

7. Limited fertilizer supply

Six groups identified fertilizer supply as a barrier to pulse production. Unfortunately we don't know which fertilizers farmers considered important, and we should not discount the idea that farmers wanted nitrogen for pulses: while the majority of farmers knew that pulses can improve soil fertility, an important fraction thought that it had the opposite impact; over 30% of focus groups from tribal villages thought that pulses had a negative impact on soil fertility, and very few farmers knew about *how* pulses could increase soil fertility. While this could be a knowledge gap, it is possible that this community is accurately assessing the impact of pulses in their cropping systems; it is possible that their fields contain inappropriate rhizobia (resulting in poor or ineffective nodulation), or insufficient phosphate for BNF.

Research to identify if appropriate *Bradyrhizobium/ Rhizobium* spp. exist in the field sites, and where necessary amendment with appropriate strains, would improve yields and mitigate the nitrogen deficiency in the system.

However, additional plant nutrients are required for pulse growth, and phosphate is especially important and commonly limited for effective biological nitrogen fixation by pulses. Limited fertilizer supply, and associated high prices, can be a major limiting factor for farmers. While India has traditionally provided subsidies for fertilizers (typically subsidizing the fertilizer at source, and distributing it through private shops), the availability of fertilizers (subsidized or not) tends to be concentrated in the main rice/wheat bread baskets of India where it often results in excessive application rates (especially of urea). Efforts to ensure that the nutrient balance of fertilizers is appropriate, and that fertilizers reach more marginal areas, are critical for sustainable pulse and food production (Praveen, 2017), something that can only be effectively done with good technical knowledge, and the financial ability to access the fertilizer, which itself increases the number of fertilizer retailers.

8. Lack of available fencing material.

Fencing is needed to protect crops from cattle, which wander freely over the fields. Local fences are made of bamboo or netting. The high cost of fencing, due to relatively small field size, stopped many farmers fencing their fields. It is unclear why fencing is required for pulses but not for other crops, for example rice is grown during the monsoon over much of the area. It is possible that the lower utilization rate of land in the off-season socially legitimizes free-roaming cattle, in which case a societal change in livestock management could overcome this barrier, or that there is a difference in distribution of vegetables compared to rice. A direct solution to a lack of fencing materials, for example provision of subsidies for fencing materials (from electric fencing to bamboo), could occur relatively discretely compared to the other barriers, but a more effective solution may be the more general provision of value (economic or food) for pulses, initiating farmer incentives to protect the fields from cattle through social or physical means.

Local Demand for Pulses

Understanding local perceptions of, and local demand for, pulses helps shine light on how the potential to produce can interact with demand. While local self sufficiency is not necessarily a positive end in itself, for isolated states such as Tripura with poor road networks and a strong demand for legumes in local diets, it is surprising that the local demand does not generate an effective local market for farmers.

The varieties with the highest local demand were red lentils and cowpea (tribal villages) and red lentils and green gram (non-tribal villages) (soybean is not grown locally and is available locally only as textured vegetable protein and so is excluded in this discussion; see **Tables 9**, **10**). Of these, red lentil offers relatively high resistance to water stress, suggesting that this demand could be met locally even with the barrier of limited water availability if other barriers such as seed and milling were overcome.

Achieving Increased Legume Production

The multiple benefits of legumes are not realized on the ground throughout India, or indeed much of the world, and while farmer barriers to legume production are described individually above, the objective of achieving optimal legume production can only be effectively addressed within the complexities of the wider food system. **Figure 2** shows some core aspects of the food system: Policy; Physical environment; and the Market/supply chain, and illustrates the complicated interactions of these with the barriers identified by the farmer. For example limited access to water, the most commonly identified barrier, is directly impacted by policy (state schemes can improve or disadvantage water availability, and training of extension officers can provide the technical knowledge for farmers) and the physical environment (from climate change to topography), but it is equally impacted by the market (national and state policies promote cereal production resulting in the displacement of legumes to un-irrigated regions). The complex interactions between these nodes seems to result in a resilient, undesirable, situation where pulses are produced at sub-optimal levels, resulting in poor soil health, inadequate soil nutrition, poor biodiversity, increased nitrogen demand and increased grain legume transport requirements.

In an ideal world, where consumers understand their nutritional needs and have the economic resources to acquire them, and farmers understand the potential of legumes and have the means to utilize them, a demand-led food production system with appropriate environmental regulations may result in optimal legume production. However, India is far from this position (and no other country in the world has achieved it). Therefore we suggest five immediate steps that can increase production even without addressing the wider system. We then go on to outline long-term systemic changes that are necessary to achieve optimal legume production.

Recommended Immediate Steps

1. **Establish a soil analysis service for farmers as part of the extension service**. This is strongly desired by farmers, and can be coupled with wider education (see below). In addition to standard soil quality parameters, we recommend analysis of

rhizobia, so that the presence/absence of appropriate rhizobial strains for different legumes can be identified. Quality control is critical, so we strongly recommend strict, independent, quality control aspects.

2. **Farmer education**. Farmer education should focus on key knowledge gaps that can work independently of the wider food system; specifically training in the nitrogen fixing abilities of legumes, and the relevant micronutrients and rhizobia requirements. This would fit well with recommendation 1 above.
3. **Training farmers in seed storage**. While new, virus free, improved variety, seeds would be optimum for farmers, the ability to plant, at the right time, appropriately stored home saved seeds substantially outweighs the existing situation of no seeds available to all. Domestic seed saving, with appropriate training, can be done simply and cheaply.
4. **Kick start a local grain legume market**. While education and home saved seed can encourage greater domestic production, they are inadequate alone to generate large scale pulse production. However, the establishment of a local market for pulses could rapidly solve this. The presence of a local market for grain legumes would address many of the barriers identified by farmers. The state government already distributes considerable quantities of grain legumes through the schemes including the public distribution system and midday meals. If part of the tender process for these schemes prescribed local procurement, building over 5 years to 100%, this would precipitate initiatives that result in farmers growing legumes on higher quality land. Importantly, purchasing centers should be decentralized to encourage integrated cropping over wider areas. Wider local market actions such as including a mill at every purchasing center could further initiate local demand, and if the policy was trusted, local entrepreneurs may provide such a service.
5. **Barrier analysis for other actors in the grain-legume supply chain**. While this paper has focused on the production barriers to pulse production, analysis along the pulse supply chain (including traders, millers and government suppliers) would elucidate other actions that could encourage the generation of an effective local pulse market.

Recommended Long-Term Steps

To achieve optimal levels of legume production an integrated, multi sectoral approach and analysis will be needed, the scope of which is beyond this paper. However, it is clear that this will include changes to the policies and subsidies that have marginalized legume production; improvements to infrastructure to facilitate the supply chain; investment in research and technology from improved water management to identification of appropriate rhizobial strains; a major investment in effective extension to farmers; and finally the effective linking between health and agricultural policies.

CONCLUSIONS

Increasing local pulse production is critical to achieve sustainable and healthy diets, especially when they are as geographically and infrastructurally isolated as Tripura. Existing efforts to stimulate increases in pulse production have been based on technical barriers identified by experts, and have largely failed. This research took a different approach to this problem, talking to the farmers about why they don't grow more pulses rather than analyzing and imposing solutions from outside.

The farmers identified twenty-eight barriers to legume production, including eight principal barriers: water management; soil fertility; seed supply; lack of technical knowledge; financial constraints; limited fertilizer supply; lack of processing units and fencing. These barriers are complex and overlapping and originate from system level failures to sufficiently prioritise grain legumes compared to cereals. Consequently they cannot be effectively addressed in isolation—there were multiple examples of interdependency between them, and they were impacted by diverse aspects of the wider food system: Policy, the Environment, and the Market/supply chain barriers. The integrated nature of these barriers explain why they have not been solved in the past, as efforts to address just one aspect fail due to the resilience of the wider system where other barriers inhibit increased pulse production. We have identified five steps that, while insufficient to enable optimal pulse production levels, we expect will have the potential to make a substantial change in the short term while efforts are made for the longer term, systematic changes, required for a fully sustainable food policy. These are: establish a soil analysis service–so that farmers and policy makers know about core yield limiting qualities of soils and how to remedy them; farmer education on the qualities of pulses, including their potential for biological nitrogen fixation; teaching farmers how to store seeds to overcome a critical yet simple barrier to production: kick starting a local grain legume market through procurement policies to government food schemes. although phased in to allow the market to grow; and finally extending the analysis of barriers to other actors in the legume supply chain.

Although our survey was carried out in a single state, the barriers identified are likely to be similar in neighboring areas of India, Nepal and Bangladesh, where socio-economic and environmental conditions are similar. Our conclusions can inform decision makers across the region.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of CU ETHICS, Coventry University Ethics Committee. The protocol was approved by the CU Ethics Committee. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

BS conceived and designed the study, framed and co-authored the paper contributing to Introduction, Methods, Discussion and Conclusion. AG-H conceived study, framed and co-authored the paper contributing to Introduction, Discussion and Conclusion. SC managed field work and collected data, analyzed data, co-authored the paper contributing to Methods and Results and commented on other sections. PB designed the study, co-authored the paper commenting on all sections.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2018.00102/full#supplementary-material

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