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Harnessing Implementation Science and Self-Determination Theory in Participatory Research to Advance Global Legume Productivity

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There are many challenges associated with increasing global legume production, and to overcome them will require stakeholders to modify certain perceptions and behaviors. Unfortunately, stakeholder motivation has been under-appreciated in global legumes research, despite its central role as a predictor of research uptake. Observational studies exist but often, motivation theory is wielded with a lack of conviction, and intervention studies have not yet emerged. Thus, participatory intervention research that embeds insight from contemporary understandings of motivated behavior, is a fruitful line of investigation. Participatory/transdisciplinary, reflective learning methodologies have demonstrated an ability to create new, and maximize existing, pathways to impact in legume productivity. Conversely, successes from the burgeoning field of implementation science have yet to be translated to agriculture research; frameworks exist that simplify the researcher's task of planning, applying, reporting, and replicating their transdisciplinary research. This review describes a novel methodological approach which promotes cross-fertilization of ideas between scientific, extension, farmer, and industry co-actors, engendering a dynamic learning culture; partners co-plan, co-execute, and co-disseminate their work together, in an equitable arrangement. This ensures that outputs are targeted to the needs of end-users and that both scientific and practical (local) knowledge is taken into account. Despite a recent proliferation of useful articles on knowledge co-creation in sustainable agriculture, this review is the first to rationalize to researchers the need to design participatory research which is informed by social psychology (Self-Determination Theory) and adheres to procedures championed in implementation science (e.g., feasibility and fidelity studies, systematic reporting). Theoretical rigor is added to the participatory research agenda, but this review also offers some practical suggestions for application in legumes research. While the focus is on legumes, this guidance is equally applicable to other crops and agricultural systems.

Keywords: motivation, participatory, implementation, uptake, barriers, solutions, self-determination, legumes

INTRODUCTION: GLOBAL CHALLENGES

Among the global challenges facing humanity, providing food security for a growing population, addressing climate change through reducing production and release of greenhouse gases, and securing sustainable and renewable sources of energy feature strongly (see UN Sustainable Development Goals two, thirteen, and seven, respectively; sustainabledevelopment.un.org/). Legumes can play a central role in addressing these challenges through: the provision of nutrient rich diets for humans and livestock; fixing atmospheric nitrogen via rhizobial symbiosis, consequently contributing to improved soil quality, reduced need for synthetic nitrogen fertilizers and the fossil fuels associated with their production; providing feedstock for biofuel production and other industrial processes; contributing soil nutrition, biodiversity and biocontrol benefits to the sustainable intensification of farming in developing countries and in sustainable mixed farming systems in currently intensively farmed regions (e.g., Europe and North America). Forage legumes in particular, as part of sustainable grassland-based animal production, can contribute to addressing these challenges by increasing forage yield, mitigating and facilitating adaptation to climate change (as elevated atmospheric CO_2, higher temperatures and drought-stress periods increase), increasing the nutritive value of herbage and raising the efficiency of conversion of herbage to animal protein (Lüscher et al., 2014; Watson et al., 2017).

The *Potential* Contribution of Legumes to Address Pressing Global Challenges

Despite so many potential benefits associated with the increased use of legumes, numerous significant challenges will have to be overcame if this strategy is to be realized. Of the total global plant protein produced, less than half is used for human consumption (Forum for the Future, no date) and this includes high quality soya protein which could be used for human nutrition. The shift toward industrialized animal farming systems creates significant demand for grain and other plant proteins as feed for animals, as well as contributing to production challenges of waste, pollution, deforestation, greenhouse gas (GHG) emissions, and soil degradation. The recent rise in prices of grain legumes due to this livestock feed demand has also led to an increase in demand for legumes worldwide through both income and population growth (Nedumaran et al., 2015). In addition to this increased nutritional demand, there is also a significant demand for soya in the bio-diesel industry. Nedumaran et al. (2015) predict that based on these changing demands, there will, in the near future, be substantive shifts in the utilization patterns and price structure of grain legumes. Interested readers are referred to existing reviews which compare global legumes production statistics, document historical trends, and discuss the hypothetical implications (cf. Asner et al., 2004; Lüscher et al., 2014; Nedumaran et al., 2015; Phelan et al., 2015; Stagnari et al., 2017; Watson et al., 2017).

There is general agreement on the potential of legumes to provide a healthy, affordable, and sustainable contribution as a food source for humans (cf. Lüscher et al., 2014; Polak et al., 2015; Ivarsson and Wall, 2017; Joshi and Rao, 2017; Mottet et al., 2017; Röös et al., 2018). However, challenges associated with realizing this potential include variable and low yields, poor seed availability, lack of market, low awareness of indigenous legumes, and the lack of convenient food applications (Philips, 1993; Mtambanengwe and Mapfumo, 2009; Mhango et al., 2012), shifting consumer preferences away from meat-heavy consumption, educating consumers about how to cook legumes and integrate them into their staple diets (Bezner Kerr et al., 2010; Polak et al., 2015), empowering women as agents of improved nutrition outcomes, taking local contexts into account and providing small producers with support to capitalize on changing market demand for delivering agricultural and nutritional improvements (Hawkes and Ruel, 2008).

With regards legumes as biofuels, research has intensified into the use of second generation biomass feedstocks (Timilsina et al., 2010; Carriquiry et al., 2011), for example, crop residues, wood residues, and dedicated energy crops such as perennial legumes, cultivated primarily for the purpose of biofuel production (Ben-Iwo et al., 2016). Perennial legumes—including alfalfa, clovers, various tree (e.g., *Pongamia pinnata*), and shrub legumes—are not only non-competitive with human nutrition, they also have the benefit of being able to grow in marginal soil and climatic conditions, fix rhizobial nitrogen, and also provide a source of protein for grazing livestock (Jensen et al., 2012). If numerous barriers to their development can be overcame (e.g., long reproductive cycle and genetic variability of cross pollinated tree legumes), it is environmentally, economically, socially, and politically beneficial (the "Quadruple Bottom-line") to grow this group of plants in nutritionally depleted and stressed soils and use them for purposes such as biomaterial and biodiesel/biofuel feed stock production (Biswas et al., 2011).

Oft-cited benefits of the use of legumes in cropping systems center on sustainability and climate resilience outcomes. For example, legume-based systems can convey advantages to soil fertility, water quality, the requirement for N fertilization in subsequent crops, weed regulation, pest and disease mitigation, reduced GHG emissions, increased light interception, and more (Barbery, 2002; Peoples et al., 2009; Jensen et al., 2012; Ngwira et al., 2012; Seymour et al., 2012; Voisin et al., 2014; Preissel et al., 2015; Stagnari et al., 2017; Watson et al., 2017; Kinama and Habineza, 2018). Unfortunately, the magnitude of the impact varies across legume species, soil properties and climatic conditions (Stagnari et al., 2017). Moreover, reports from varied farming contexts indicate that significant concerns and barriers exist around technical knowledge, management skills, poor seed availability, perceived (and often realized) low and variable yields, inadequate policy support, lack of markets, lack of proper quantification (and recognition) of long-term benefits of legumes within cropping systems, lack of persistence and stress tolerance (temperature, N, phosphorus and water), nodulation efficiency, and the supply of seed of adapted varieties with appropriate inoculant (Mtambanengwe and Mapfumo, 2009; Ncube et al., 2009; Peoples et al., 2009; Bues et al., 2013; Preissel et al., 2015; Stagnari et al., 2017). In an attempt to address the challenge associated with the availability (production and dissemination) of good-quality seed initiatives such as the Alliance for a Green

Revolution in Africa (AGRA) established the Programme for Africa's Seed System (PASS), though the impact of this system at grass roots level is yet to be evaluated.

The overall picture is one of a research area in need of a coherent strategy to expedite uptake and impact; the *potential* advantages—or hypotheses—of increased global legume productivity touched upon above (and reviewed extensively elsewhere) must be tested using methodologies that give research its best chance of generating knowledge that is quickly translatable into policy and sustainable practices. Good participatory legumes research certainly exists (Payne et al., 2017) but still, questions persist about uptake, impact, and sustainability. As such, the purpose of the present review is to rationalize and provide practical suggestions for a novel, more theoretically rigorous approach to participatory legumes research: harnessing insight from implementation science and Self-Determination Theory will help researchers to establish the organizational and collaborative conditions in which each knowledge co-creation projects fulfills its ambition.

RESEARCHING SOLUTIONS TO THE SIGNIFICANT CHALLENGES ASSOCIATED WITH INCREASING LEGUME PRODUCTION

A gradual philosophical shift is being witnessed in the agriculture literature: more and more qualitative, participatory, and psychologically-informed research is slowly being published, and the number of journals that support this philosophy is increasing (e.g., *Journal of Agricultural Development & Policy*, *Journal of Rural Studies*, *International Journal of Agricultural Extension & Rural Development*). However, traditional approaches to research still predominate, characterized by hegemonic power hierarchies and beneficiaries-as-passive-recipients of the researcher's scientific expertise. Furthermore, poor uptake of legumes research can be interpreted as a residual effect of previous research and dissemination that was not grounded in knowledge co-creation approaches. The limited cultivation of legumes raises the question of how farmers can be engaged and motivated to commit resources to overcoming these challenges. An obvious approach, given political will, would be to provide subsidies for legume production. However, subsidies have themselves proved to be a problematic market intervention and often produce unintended consequences. Cowe (2012) points out that "subsidies given to farmers as part of the CAP are blamed for encouraging intensive farming that degrades land, water and habitats. Similarly, rich-world subsidies, like the CAP, make life even tougher for poor farmers in developing countries" (NB, The European Union's Common Agricultural Policy, or CAP, is "a partnership between agriculture and society, and between Europe and its farmers;" see https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-glance_en). The challenge is to find interventions that work for, rather than against, the environment and international development. In other words, how can researchers design interventions that can be adapted and scaled up in ways that are accessible and equitable? What insights from social psychology can contribute to addressing the challenge and motivating farmer engagement? To find answers to these questions, we look to Self-Determination Theory, implementation science, the participatory research paradigm, and a novel integration of all three.

Harness Insight From *Self-Determination Theory* Regarding Human Motivation and Behavior

Self-Determination Theory (SDT) is a broad theoretical framework that explains human motivation and the functions of personality (Deci and Ryan, 1985, 2000; Ryan and Deci, 2000). Research has applied SDT in a range of domains (e.g., organizations, religion, education, health, medicine, sport, and physical activity) and a vast literature supports its explanatory and predictive utility. *Self-determination* refers to the degree to which individuals feel that their behavior is controlled vs. autonomous, and SDT posits contrasting motivational consequences associated with this perception (i.e., positive vs. negative). SDT is comprised of six mini-theories, of which *Cognitive Evaluation Theory*, *Organismic Integration Theory*, and *Basic Psychological Needs Theory* can be especially helpful in understanding the psychology, behavior, and by implication performance, of stakeholders in legume production.

Cognitive Evaluation Theory is concerned with *intrinsic motivation*, which is "the innate, natural propensity to engage one's interests and exercise one's capacities, and in so doing, to seek and conquer optimal challenges" (Deci and Ryan, 1985, p. 43). Human development, as characterized by learning, adaptation, and a growth in competencies, is greatly facilitated by intrinsic motivation (Deci and Ryan, 1985). Interest and intrinsic motivation can be supported or thwarted by one's social context, and in particular, the presence of factors such as environmental controls and rewards. Theoretically, farmers who feel that they operate within a controlling system, where rewards are dependent on behaviors that they do not truly believe in, or where there are constraints on their opportunities to exercise their capacities—to learn, adapt, and grow—are unlikely to experience intrinsic motivation, and might instead suffer from disinterest and stagnation (cf. Deci and Moller, 2005). For example, market forces that encourage specialization in Soya beans (Stagnari et al., 2017) might stifle farmers' desire to master a mixed legume farming system. Similarly, researchers should employ participatory methods to produce solutions that are *co-created* with farmers and other stakeholders, thereby supporting their intrinsic motivation and maximizing eventual uptake of the research.

On the other hand, Organismic Integration Theory focuses on *extrinsic motivation*, which is reflected in behavior that serves an instrumental purpose rather than being done "for its own sake" (Ryan and Deci, 2002). According to Organismic Integration Theory, the instrumental purposes underpinning behavior are less or more extrinsically motivating depending on how *internalized* or *integrated* they are to the individual's sense of self. The less internalized forms of instrumentality are characterized by the salience of extrinsic rewards or punishments to the individual, their perception of the need for compliance in the situation, and/or a focus on approval from self or others (Ryan and Deci, 2000). For example, in Thailand, public standards of good agricultural practices have been established, but most farmers "do not understand the underlying rationale for these guidelines and therefore do not feel intrinsically motivated to follow them, but rather perceive the guidelines as requirements that need to be fulfilled explicitly and exclusively for the audit" (Schreinemachers et al., 2012, p. 525). In stark contrast, more internalized forms of instrumentality are characterized by a conscious valuing of the activity, self-endorsement of goals associated with the activity, and/or a sense of congruence between the activity and one's sense of self (Ryan and Deci, 2000). Effective farming relies on a set of conditions and behaviors that are instrumental (extrinsically motivated) to the goal of keeping the farm running (e.g., early mornings, long hours, low pay, grueling manual labor, often isolation), but unlikely to achieve the status of an intrinsically motivated behavior (e.g., done for enjoyment). On the other hand, farmers *may* experience "integrated regulation"—the least extrinsically motivating force—because their work responsibilities are integral to their core identity and help fulfill their basic psychological needs (BPNs) (see below; NB: "Farming is much more than an occupation: it is the reproduction of the family; it is work; it is their public role; it is their social status; and, it is their self-image. These multiple layers of meaning combine in such a way that the work of farming becomes an end in itself and survival its own logic," Pile, 1990, pp. 160–161).

In some cases, extrinsically motivated behavior can be difficult to sustain in the long term because the effects of the external inducements tend to "wear off" (cf. Deci and Moller, 2005; NB. perhaps the extrinsically regulating force is a particular policy, and the policy changes). CAP payments in the EU are an example of an external incentive to keep one's farm running, but that and similar motives do not necessarily filter down to *motivated behavior* on a day-to-day basis; theoretically, extrinsic motivation can contribute to more frequent lapses in any behavior, to the detriment of the desired goal (see Vande Velde et al., 2018, for an excellent discussion of the perils of regulation and economic rationality as extrinsic regulators of farmers' use of anthelmintic treatment strategies). Implementing a crop rotation suggestion that is based on research evidence is an example of behavior *change*, specifically: although the behavior serves instrumental purposes (e.g., increased income), the farmer is more likely to sustain the new practice if they are assisted to quickly internalize and integrate it into their *modus operandi*, as contrasted with feeling impelled to do it or otherwise controlled. To evidence the importance of this theory, legume production research could compare pertinent outcomes for carefully matched participant groups that either receive or do not receive an SDT-informed version of a legumes trial. These theoretical principles warrant investigation in a general sense but also in diverse agricultural contexts—developed vs. developing countries, for example, where the factors regulating farmers' behaviors might look different on the face of it, but *should* follow these SDT tenets nonetheless.

Some published studies rely on the psychological construct of intrinsic motivation (cf. Greiner and Gregg, 2011; Mzoughi, 2011; Besser and Mann, 2015; Greiner, 2015; Carlisle, 2016) but too often do not theoretically define it, do not refer to the SDT or Cognitive Evaluation Theory formulation, confound motives and motivation, and/or confound intrinsic and extrinsic motivation. For example, Kessler et al. (2016) documented an "integrated soil fertility management" intervention that was tested in Burundi, the aim of which was to foster "farmers' intrinsic motivation to invest in activities that make the household more resilient and profitable, while moving toward sustainable agricultural intensification" (p. 249). Referring to the above definitions of intrinsic motivation, however, will make it clear that these are not intrinsic regulators of behavior (they are instrumental motives and therefore more extrinsic). A non-SDT but nevertheless interesting example is provided by studies on farmers' adoption of conservation actions in the context of land management and land use (cf. Pannell et al., 2006; Farmar-Bowers and Lane, 2009): behavioral decisions are often made for what Cognitive Evaluation Theory would consider to be instrumental, and thus extrinsically motivated, reasons (e.g., to make money which secures a stable family lifestyle). Conversely, many farmers choose to build long-term soil health for non-economic reasons, such as environment protection, land conservation, and to "do right by my downstream neighbors" (Carlisle, 2016). Cognitive Evaluation Theory would theorize that these farmers have integrated such behaviors into their sense of self, and the behavior is at the lowest end of the extrinsic motivation spectrum.

Pertaining to a smallholder dairy development project in Kenya, Uganda, and Rwanda, Kiptot et al. (2016) investigated the motivations of volunteer farmer-trainers, which is a community-based extension approach. Kiptot et al. (2016) observed that the farmers and trainers were generating income from inputs and services associated with the training activities. They were concerned that this conflicts with the volunteerism philosophy of the scheme, and the introduction of rewards would undermine the trainers' intrinsic motivation over time (leading to their withdrawal from the scheme). Lioutas and Charatsari (2017) designed a questionnaire to assess farmers' motives for the adoption of "green innovations." Whilst the study was not explicitly grounded in Cognitive Evaluation Theory, a factor emerged which captured boredom and lost interest. Lioutas and Charatsari labeled this sub-scale, "Need for change," and it is interpretable in SDT terms as the farmer's drive to seek and conquer new challenges, to learn, adapt, and grow in their competencies (Deci and Ryan, 1985).

Other studies *have* explicitly employed Cognitive Evaluation Theory to interpret farmer intrinsic motivation and behavior. Herzfeld and Jongeneel (2012) argue that, in some cases, the introduction of incentives and penalties (extrinsic forms of motivation) can detract from a farmer's intrinsic motivation to participate in voluntary EU agri-environmental schemes and comply with EU regulations. Similarly, Kvakkestad et al. (2015) argued that the "the wider meaning of being a farmer"—representative of the integrated form of extrinsic motivation—is often more important than profit maximization. In Luhmann et al. (2016), dairy farmers demonstrated long-term willingness to participate in an initiative to promote high animal welfare standards. Where financial inducements were reported as a weak motivator, and/or farmers were willing to adhere even if they incurred additional costs, Luhmann et al. (2016) interpreted this behavior to reflect personal belief in the sustainable activities, appreciation of society's recognition of their commitment to the standard, and/or a sense of personal joy stemming from taking responsibility for the welfare of their animals. Unfortunately, the authors confound a lack of financial motivation for the behavior to indicate an intrinsic motivation to do it, which is a limited view of Cognitive Evaluation Theory and Organismic Integration Theory.

The final SDT mini-theory of interest, Basic Psychological Needs Theory, suggests that humans have evolved to seek activities which fulfill three innate needs: *autonomy* ("the need to self-regulate one's experiences and actions…associated with feeling volitional, congruent, and integrated"), *competence* ("our basic need to feel effectance and mastery. People need to feel able to operate effectively within their important life contexts"), and *relatedness* ("feeling socially connected…a sense of being integral to social organizations beyond oneself;" Ryan and Deci, 2017, pp. 10–11). The three BPNs are considered essential to human functioning, and at a universal level this relevance has been demonstrated across a variety of life domains (cf. Chen et al., 2015; Nishimura and Suzuki, 2016; Yu et al., 2018). Farmers have the opportunity to seek workplace opportunities that fulfill their BPNs, but this has not been investigated. Theoretically, for example, a farmer will function well both on-farm and off if they feel able to (1) exercise self-determination in their professional decisions (autonomy), (2) competently master those work tasks that, to them, most strongly reflect their identity as a farmer, and (3) contribute to a wider social purpose, which is inherent in the farmers' profession (e.g., environmental stewardship, combating food insecurity). Unfortunately, the converse is also true: when the farmer's BPNs are thwarted by their workplace circumstances (e.g., constraining systems, isolation), sub-optimal functioning will likely manifest (Ryan and Deci, 2000). Indeed, the scientific literature is replete with studies of farmer mental health (often negative), and a Basic Psychological Needs Theory perspective on this issue is long overdue.

Research has indirectly demonstrated that extrinsic motivators for behavior which the farmer would otherwise wilfully undertake because it contributes to a common goal they share with others, such as payments for ecosystem services, can thwart fulfillment of the relatedness BPN and cause dissatisfaction with the initiative (cf. Kerr et al., 2012; Narloch et al., 2012). Using structural equation modeling, Gyau et al. (2012) demonstrated a positive impact of Cameroonian kola producers' intrinsic motivation for engaging in collective action on their perceptions of the "ease of use" and usefulness of such activities (e.g., "group training in production and storage facilities, negotiation abilities and group marketing, and aiming to improve small-holder benefits in the value chain have been used to improve market access and bargaining power of producer," p. 43). It is possible that the farmers fulfilled multiple BPNs during this collective action, reciprocally benefiting their intrinsic motivation. Theoretically applicable to farmer-consultant dyads, it has been argued that the degree of knowledge transfer between parties is influenced by their shared understanding and personal relationship (akin to the relatedness BPN), as well as a cumulative sense of intrinsic motivation (Ko et al., 2005). Membership of community-supported agriculture activities in Wisconsin (USA) has been explained in BPN terms (Zepeda et al., 2013). In Greece, Charatsari et al. (2017b) found that farmer participation in competence development projects is, perhaps not surprisingly, associated with the autonomy and competence BPNs, as well as motivation to seek knowledge. Similarly, participation in farmer field schools was both motivated by, and helped to fulfill, farmers' relatedness BPN, especially for those whose needs were not supported prior to participation (Charatsari et al., 2017a). Triste et al. (2018) provided a compelling argument for sustainable farming initiatives (SFIs) to be underpinned by SDT. Specifically, they have supportive data for the need to both market SFIs in order to appeal to BPNs, and to design SFIs in such a way as to support farmers' autonomous motivational process, via the BPNs. Similarly, Rothmann's (2013) findings led them to urge South African agricultural organizations to train managers to support the autonomy and relatedness satisfaction of employees, as these BPNs were shown to mediate the relationship between employee-manager relations and intention to leave.

Conclusion

Farmers live with "multiple uncertainties and indeterminacies in their farming presents and futures" (Robinson, 2017, p. 168), and these transient conditions thwart self-determination (i.e., detract from the fulfillment of autonomy and competence needs, minimize the desire to internalize vocational behaviors, and remove opportunities to experience a sense of intrinsic motivation). Moreover, many of the challenges to global legumes production referred to in section Introduction: Global Challenges point to a controlling motivational climate, and the consequences to farming have been made evident. Despite its widespread and successful adoption in many other domains of human experience, there has been only small pockets of observational research that has applied SDT in agricultural contexts. Hence, some progress *has* been made to understand what regulates (motivates) farmers' behavior on a day-to-day basis, but the field requires SDT-informed intervention studies. If researchers build into their study designs the explicit aim of satisfying farmers' BPNs and intrinsic motivation, improved research uptake should follow.

Armed with the robust SDT framework and full intention to integrate it into their participatory research (see section Combining Insight From SDT, Implementation Science, and the Participatory Research Paradigm to Solve the Challenge of Increasing Global Legume Production for practical applications), legumes researchers can shift attention to the systematic use of guidance on research planning, application, and reporting from the field of implementation science. The aim is to design research methodologies that have the maximum likelihood of quickly achieving "demonstrated sustainability" status.

Learn From the Field of Implementation Science

Countless scientific studies are published each year that evaluate potentially game-changing techniques and interventions. Examples include oncology-based drug developments, health education and health promotion programmes, and innovations in agriculture. Unfortunately, the "lag" that is witnessed between the completion of research and its implementation in the field—whether it is ∼17 years in health research translation (Morris et al., 2011) or ∼30 years in agriculture (Alston et al., 2009), for example—too often renders these "solutions" redundant, or at the least, compromised. The burgeoning field of implementation science is fundamentally devoted to "the scientific study of methods to promote the systematic uptake of research findings and other evidence-based practices into routine practice" (Eccles and Mittman, 2006, p. 1), and it "…examines what works, for whom and under what circumstances, and how interventions can be adapted and scaled up in ways that are accessible and equitable" (Global Alliance for Chronic Diseases; gacd.org/research/implementation-science). The speed of research uptake is prioritized equally alongside *accurate* translation of the research, thereby helping to reduce the lags that plague applied science. Implementation science helps researchers to interrogate their design decisions, critically evaluate the outcomes of their projects, and effectively share the insight that is gained. Intended beneficiaries of research are intimately involved in the entire process and thus co-create new knowledge. Implementation science recognizes that there are many social actors with a role to play in the uptake of research into practice, the number of which—and the complexity of interrelationships within their systems—depends on each context. It is beneficial to explore how comprehensive frameworks designed to maximize uptake in natural contexts (e.g., RE-AIM, below)—and shown to be effective in other disciplines and challenges (e.g., sustainability of health interventions in Sub-Saharan Africa; cf. Iwelunmor et al., 2016)—might map over to agriculture. Specifically, if increased legume production is to help solve the global challenges outlined in section Introduction: Global Challenges, *what* research is needed to overcome the numerous barriers that have been identified, and *how* should this research be designed to create optimized pathways to impact and maximize the uptake of its findings?

Research Planning

The first step in research planning is to identify the most appropriate research approach. The traditional approach would be to leave the research to researchers in the formal Agricultural Knowledge System (AKS), which consists of agricultural research, education and extension establishments (Rivera and Sulaiman, 2009). The AKS paradigm assumes that knowledge and innovation only need to come from official science, which is free from the need to take the views, needs, and knowledge of the end users of innovation into consideration (Dosi, 1988). However, this neglect of societal actors as contributors to innovation (Leeuwis and Van den Ban, 2004; Knickel et al., 2009) reduces the capability of the AKS to address the goals of the agricultural sector or to support sustainable rural development. Systems approaches are therefore replacing the linear view (e.g., Röling and Engel, 1991; Hall et al., 2003; Sumberg and Reece, 2004; Knickel et al., 2009) and the formal institutions of the AKS have shifted toward the inclusion of farmers as important actors who participate in joint learning and negotiation to shape innovations (Leeuwis and Van den Ban, 2004). The overarching term to describe this shift is participatory research, or sometimes, transdisciplinary research, in which non-scientific stakeholders take ownership of both research and results by deciding on research objectives and strategies, while staying within the framework of scientific inquiry (Pohl and Hirsch Hadorn, 2008). Schneider et al. (2009) point out that social learning takes place when the knowledge of, in this case farmers, scientists, advisors, and other experts is integrated in a participatory process in which stakeholders and researchers collaborate to identify and rank specific problems, agreeing on methods to find the causes, and finding ways to realistically and practically solve them (cf. Bradford and Burke, 2005). Transdisciplinary research appears appropriate to meet the challenge of creating the conditions for meaningful and successful collaboration between researchers and stakeholders (Wicks and Reason, 2009; Caister et al., 2012), and is therefore clearly compatible with SDT and implementation science ("what works, for whom and under what circumstances").

There are problems—if not insurmountable—associated with participatory approaches, however. For example, participatory research is susceptible to reproducing and reinforcing existing power relationships within the participants (or ignoring women), with a common example being a hierarchical relationship between academics and the participants (Cooke and Kothari, 2001). A transdisciplinary research approach must carefully consider the implications of the processes at the local level to encourage and facilitate co-learning processes. This calls for an approach with continued reflection on the participatory process (Loeber et al., 2007), which in turn requires skills that an academic researcher might not fully possess. However, implementation science gives sufficient encouragement that the advantages of this process can outweigh its disadvantages (Pain, 2004), and harnessing SDT principles inherently breaks down power inequities.

Calls for transdisciplinary research to motivate transitions to more sustainable agriculture became loud in the late 2000s, with prominent scholars such as Aeberhard and Rist (2009) and Vandermeulen and Van Huylenbroeck (2008) highlighting its potential to elicit change. Participatory research is advocated by the European Union in its long-term strategy for European agricultural research and innovation and reflected in the substantial Horizon2020 funding stream. Common to most transdisciplinary research methodologies, in addition of course to participation of relevant stakeholders, are iteration and reflection, leading to ownership and implementation. These characteristics are evident in the following examples. Nyang'au et al. (2018) found that collaborative leadership enhanced implementation of a method using intercropping with a moth repellent fodder legume to control stem borer pest in Maize crops in Ethiopia. Sousa et al. (2016) concluded that participatory video: a transdisciplinary research method, contributed to uptake of novel composting methods by giving ownership of the video-based information, which thereby extended its outreach. Although fewer examples can be found in the literature about grain-legume production, the common themes of ownership, and sustainability suggest that such methodologies have at least the potential for application to inspire change. Indeed, Magrini et al. (2016) suggest the factors that hinder grain-legume development are primarily social rather than technical, and that engaging farmers is essential to promoting grain-legumes. SDT provides an overarching framework to understand and better promote stakeholder engagement.

A characteristic of participatory research approaches is that they consistently meet their aims. Home and Rump (2015) evaluated 17 diverse Learning and Innovation Networks for Sustainable Agriculture (LINSA) in Europe. As defined by network members (i.e., researchers and agriculture stakeholders), successful collaboration was characterized by strong internal engagement, co-development of strategy, creation of concrete outputs, equal give-and-take of benefits (new knowledge or improved practical solutions), joint reflection, mutual trust and commitment, finding a "balance between guidance and listening, interactions and freedom, and positive and critical reflection" (Home and Rump, 2015, p. 73). Implicit in such research is the need-fulfillment and intrinsically motivating properties of the collaborative research process. Many examples of impactful participatory research exist in developing countries (cf. Kangmennaang et al., 2017), and excellent guidance documents are available for this context (cf. Garibaldi et al., 2017). Unfortunately, review articles still warn that participatory research is not a widespread as might be expected and suitable evaluation measures are inconsistently employed (Schindler et al., 2015; Smith et al., 2017). This is especially true in the vital areas of innovation platforms and technology adoption.

Participatory research offers clear advantages over traditional approaches in crop and animal science, but still, little participatory research has explicitly addressed stakeholder motivation to the level of theoretical rigor afforded by SDT. In terms of increasing global legume production, researchers who perhaps lack confidence in participatory methods (cf. Payne et al., 2017) or awareness of the mechanisms by which they work (e.g., social learning theory, SDT), are urged to treat the present article as a catalyst to gain further methodological experiences in the integration of SDT, participatory approaches, and implementation science procedures (see section Combining Insight From SDT, Implementation Science, and the Participatory Research Paradigm to Solve the Challenge of Increasing Global Legume Production).

Research Application and Reporting

RE-AIM (cf. Glasgow et al., 2019) stands for: Reach (the intervention's target population), Effectiveness (or efficacy, of the intervention), Adoption (the population who are willing to initiate the intervention), Implementation (consistency, costs and adaptations made during delivery), and Maintenance (of intervention effects in individuals and settings over time; see **Figure 1** for more detail). The RE-AIM framework would help focus the researcher's attention if they wanted to investigate, for example, the high variability in yield and susceptibility to biotic and abiotic stresses of grain legumes (Nedumaran et al., 2015); it facilitates an examination of *what works*, *for whom* and *under what circumstances*, and "how interventions can be adapted and scaled up in ways that are accessible and equitable." Despite its widespread use in other fields of applied research, an early 2019 Google Scholar search of academic publications since 2015 using the term "re-aim 'AND agriculture OR farming"' (minus patents and citations) provided just 321 hits, and very few were related to food production. The RE-AIM framework assists stakeholders to (i) organize the results of their research for reporting, (ii) translate their research into practice, (iii) organize reviews of existing literature, (iv) plan programs with an enhanced chance of achieving impact in the field, and (v) weigh-up and understand the relative (hypothetical) costs and benefits of taking alternative approaches to a single challenge. All of these aims are pertinent to researchers interested in increasing legume production to meet the global challenges of food insecurity, climate change resilience, and sustainable energy. In sum, then: "The overall goal of the RE-AIM framework is to encourage program planners, evaluators, readers of journal articles, funders, and policy-makers to pay more attention to essential program elements including external validity that can improve the sustainable adoption and implementation of effective, generalizable, evidence-based interventions" (www.re-aim.org). So-called "essential program elements" (e.g., clearly defined primary and secondary outcome measures and the levels at which they were measured, how sample size was determined, baseline demographic and clinical characteristics of each group, number of study units in each group included in each analysis, sources of potential bias or imprecision) can be incorporated into applied research in legumes production by working *backwards* from a checklist of information to include when reporting a feasibility or full randomized controlled trial (RCT) trial.

The REFLECT statement (Reporting guidElines For randomized controLled trials for livEstoCk and food safeTy; Sargeant et al., 2010) is an evidence-based checklist of items that should be included when a RCT is reported with production, health, and food-safety outcomes (www.reflect-statement.org). REFLECT, much like the CONSORT statement from which it was adapted (Consolidated Standards of Reporting Trials; Altman et al., 2001; Moher et al., 2010), is much more than a list to facilitate the transparent reporting of an RCT; it is an a priori guide to the level of methodological rigor that is required for a study's findings to have a chance at being implemented in the field. Following these recommendations can mitigate against the "startling lack of consensus amongst experts about how best to measure agricultural sustainability" (de Olde et al., 2017, p. 1327). Where a full RCT is not suitable, and a pilot or feasibility trial is the best option (albeit still randomized), legumes researchers can refer to the appropriate CONSORT extension (Eldridge et al., 2016) and modify the REFLECT checklist accordingly.

Feasibility and fidelity work should be an essential component of legumes research, just as is it in the most impactful medical and psychological research (Cohen et al., 2008; Gearing et al., 2011). A thorough feasibility study would assess stakeholder enthusiasm for the project and the probability of successful recruitment to it (including participant adherence and retention), predict associated risks and determine the safety of participants, and

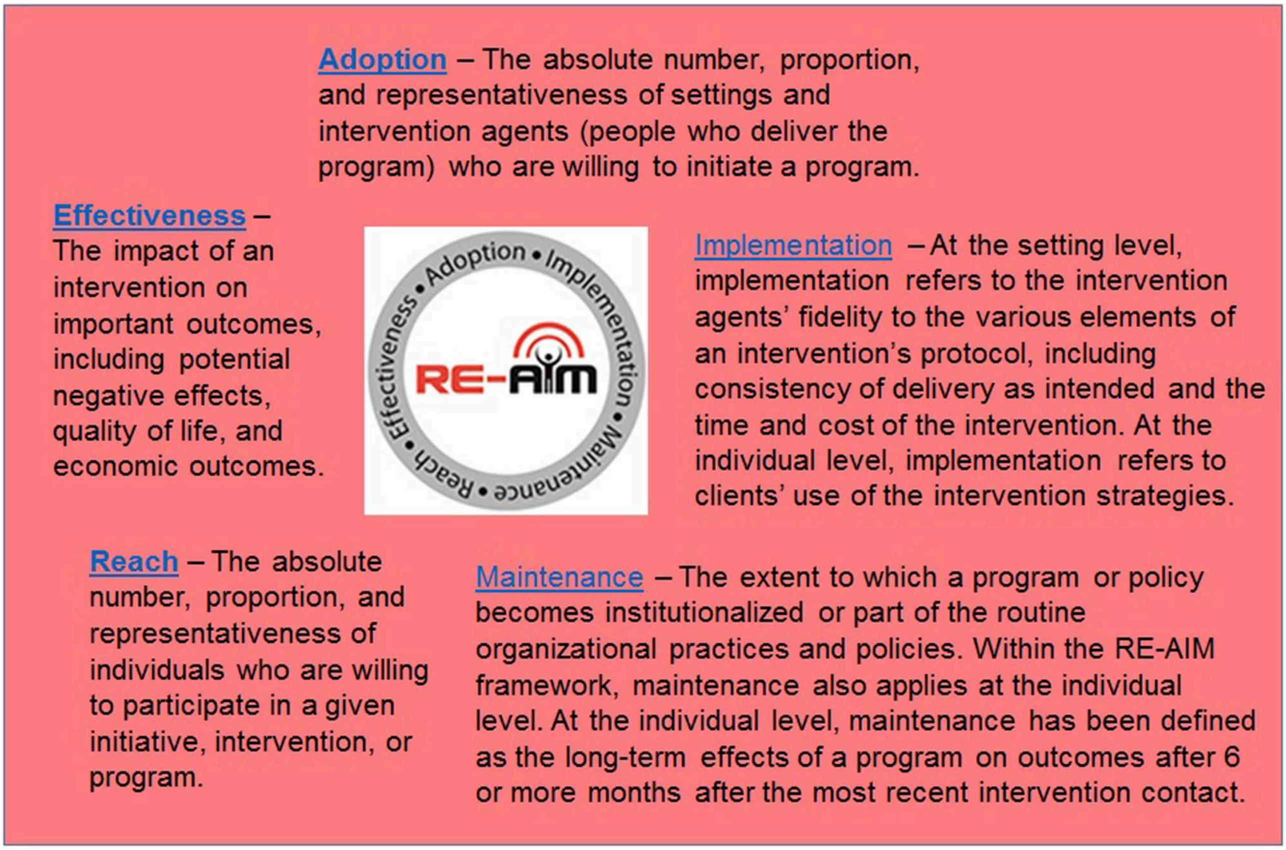

FIGURE 1 | The RE-AIM framework (http://www.re-aim.org/about/frequently-asked-questions/).

increase researcher experience with the intervention methods; it would investigate economic, market, technical, financial, and management aspects of feasibility (cf. Van Hemelrijck and Guijt, 2016). As such, a feasibility study can protect against potential misallocation of research funds and establish strong foundations for a project's eventual success. Feasibility studies would be essential in translating findings from the laboratory to help farmers increase utilization of locally grown, less commonly demanded varieties of legumes that will be affordable for low income families, for example.

Intervention fidelity refers to those "back-stage" factors which influence the outcomes of the intervention, whether a feasibility/pilot trial or RCT. A trial may work perfectly in the laboratory and even the field, but will the farmer maintain the corresponding behaviors once the study closes? The answer depends on many factors, of course, including their self-determination (section Harness Insight From Self-determination Theory Regarding Human Motivation and Behavior), but *how* the intervention is delivered is also vitally important (cf. Cook and Thigpen, 2019). For example, if a participatory project seeks to help willing farmers who are used to farming monocultures to include grain legumes in cropping sequences (cf. Stagnari et al., 2017), this represents a behavior change intervention and detailed reporting is required of (i) how training providers were themselves trained, (ii) the credentials of the trainers and providers, (iii) the theoretical model on which the behavior change intervention is based (e.g., SDT), (iv) a method to ensure that the content of the intervention was being delivered as specified, (v) a mechanism to assess whether the providers adhered to the intervention plan, and (vi) assessment of farmer comprehension and implementation of the intervention during and beyond the study period (see Borrelli et al., 2005 for full guidance). Without such detailed reporting, how can future researchers hope to replicate the positive results, or identify where things did not work so well in an intervention? Hence, fidelity should be treated as a core component of intervention research and stimulate detailed reporting of factors which influence the probability of eventual uptake by stakeholders.

RE-AIM, the REFLECT statement, and associated concepts of intervention feasibility and fidelity have a theoretically sound basis for upskilling researchers: they are grounded in reliable evidence and provide sufficient detail to raise the researcher's self-efficacy for the challenge of comprehensive and transparent study design and implementation. Indeed, it is worth exploring the research question that the integration of these approaches would also help researchers and partners fulfill *their own* needs for competence and autonomy within a participatory legumes production project. Despite this, the REFLECT statement has not been adopted to anywhere near the same extent in agriculture as its parent approach (CONSORT) has in health and medicine. Indeed, the CONSORT statement has been cited more than 8000 times (Eldridge et al., 2016), and its use is associated with an improvement in the quality of reporting of RCTs in these fields (Turner et al., 2011). In medicine, poorly designed and/or reported RCTs can lead to overestimation of the treatment effect, diminished quality of pooled analyses (e.g., meta-analyses), and impaired clinical practice decisions (cf. Moher et al., 1998; Péron et al., 2012); parallels to crop and animal science can be made and should not be ignored, and the REFLECT guidelines can address this concern.

In conclusion, implementation science urges researchers to adhere to a systematic process, from the conception of a research idea through to dissemination and monitoring of uptake. Such an approach, while more prescriptive than typically seen in agriculture, does not mean that the research team loses flexibility to manage factors as they unfold on the ground during research in complex scenarios. Participatory research imbued with SDT compensates for this, but the implementation science frameworks add a level of ("meta") rigor. Existing frameworks which facilitate this process in health/medicine research translation can be modified to suit the legume production context at hand; legume research planning, transparent reporting, and replication efforts will benefit.

COMBINING INSIGHT FROM SDT, IMPLEMENTATION SCIENCE, AND THE PARTICIPATORY RESEARCH PARADIGM TO SOLVE THE CHALLENGE OF INCREASING GLOBAL LEGUME PRODUCTION

A commitment to RE-AIM, the REFLECT statement, and the need for intervention feasibility and fidelity work will provide participatory legume projects with a greatly enhanced chance of success, whether they want to (i) explore the challenges associated with increasing legumes production, (ii) explore the feasibility of hypothetical solutions to known challenges (i.e., prior to RCTs), (iii) test hypothetical solutions to known challenges (i.e., fidelity studies, RCTs), (iv) test the sustainability of a demonstrated solution, and/or (v) design follow-up research where a viable solution demonstrated non-sustainability in the field. The suggestions made in section Learn From the Field of Implementation Science provide a clear "road map" for incorporating insights from implementation science into legume research. Crop scientists may find the concept of harnessing stakeholder psychology a more challenging prospect, however. Section Harness Insight From Self-determination Theory Regarding Human Motivation and Behavior rationalized the importance of self-determination in agriculture: full volitional stakeholder engagement in legume production research, from study conception through dissemination of results to the evaluation of impact, would theoretically stimulate an internalization of the science that underpins the research (Baard et al., 2004; Gagné and Deci, 2005). Thus, the behaviors required of farmers to implement the findings of the research into routine practice would become intrinsically motivated, and therefore sustainable (cf. Pelletier et al., 2011). Farmers' direct involvement in framing the research questions and informing project modifications via real-time feedback would foster a sense of autonomy; being involved in a constructive two-way dialogue with the project's science and industry partners would foster a sense of competence and relatedness; fulfillment of these BPNs is associated with intrinsic motivation and optimal human functioning (Deci and Ryan, 2000; Ryan and Deci, 2000). Farmers who are asked to implement recommendations from research that did not include them in the decision making process, are less likely to internalize the necessary behaviors—via a thwarting of their BPNs—and this extrinsic, controlling sense of motivation is difficult to sustain. Indeed, farmers in many regions already have to cope with structural issues over which they have little control (e.g., non-availability of quality seed, prohibitive market structures, poor funding mechanisms), but SDT-informed research can at least assuage this cold reality and help farmers work around such constraints. Section Combining Insight From SDT, Implementation Science, and the Participatory Research Paradigm to Solve the Challenge of Increasing Global Legume Production will describe how legumes researchers can make their first foray into SDT-informed participatory methodologies.

Practical Tools to Harness Stakeholder Psychology

In workplace, education, and healthcare contexts, SDT-based interventions have proven effective with managers, teachers, and healthcare practitioners, respectively; such leaders can be trained to communicate and behave in a way that satisfies their employees'/students'/patients' BPNs, and this is associated with an increase in their intrinsic motivation in the context, enhanced task engagement, satisfaction, and performance (Baard et al., 2004; Williams et al., 2006; Entwistle et al., 2010; Su and Reeve, 2011; Cheon et al., 2012). Autonomy-supportive communication, in particular, is key to promoting optimal conditions for success, and is a leader and team member characteristic that can be trained. When autonomy support is emphasized in a working relationship, collaborators tend to experience a sense of being "in synch" with each other, where the behaviors of one member are understood to influence the behavior of many others (Reeve et al., 2004; Lee and Reeve, 2012). Each partner in a legumes production project is integral to its success and the project will rely on reciprocal knowledge sharing: legumes research leaders are encouraged to build autonomy support training for all partners into their research plans (and funding applications).

Prior to a project's first formal meeting, all partners (farm, industry, extension, science) are encouraged to communicate on a secure online forum to "get the conversation started" about their legumes challenges, both common and unique (autonomy support and promotion of relatedness). In project meeting number one the work package members and farmer network representatives could receive training on how to promote need fulfillment and intrinsically motivating opportunities in their work with all project partners. Such training represents the primary mechanism by which the researchers will ensure that the project influences stakeholder behavior in a sustainable way: possessing a logical rationale and a sense of competence for the associated tasks is important if one is to invest time and energy to a new course of action; and if the behavior is to be maintained, a sense of self-determination is absolutely vital (cf. Deci and Ryan, 1985, 2000). This training will also cover the proper use of suitable tools for monitoring the psychological outcomes associated with the methodology (e.g., farmers' autonomous motivation, need fulfillment; see section Measurement Tools to Help Legumes Researchers Assess Progress and Project Outcomes).

Measurement Tools to Help Legumes Researchers Assess Progress and Project Outcomes

SDT has been extensively applied in a variety of applied research contexts. Associated with this activity is the availability of well-validated measurement tools that tap SDT constructs such as the behavioral regulations (intrinsic through to extrinsic forms) and BPNs. For example: (1) basic psychological need satisfaction and frustration scales (BPNSFS) assess the degree to which people feel that their BPNs of autonomy, competence and relatedness are being satisfied, and this is important because need satisfaction is associated with well-being whereas need frustration is associated with ill-being (Chen et al., 2015). Domain-specific BPNSFS exist (education and physical education, relationships, training, sport, physical exercise, work), and while an agriculture version has yet to be constructed, the work domain version will certainly suffice in the meantime (cf. Kasser et al., 1992; Ilardi et al., 1993; Deci et al., 2001); (2) the "Work Climate Questionnaire" (WCQ; Baard et al., 2004) asks respondents to indicate their perception of the autonomy support provided by a target other (e.g., their manager or work package leader) or group (e.g., organization), and its wording can be adapted to suit the particular situation; and (3) self-regulation questionnaires tap into the reasons why individuals *do* a certain behavior, i.e., for relatively controlled (*external* and *introjected*) or autonomous (*identified* and *integrated*) reasons (cf. Ryan and Connell, 1989; Williams and Deci, 1996; Black and Deci, 2000; Ryan and Deci, 2000). The SDT-based constructs measured by these scales have consistently demonstrated expected positive or negative relationships with certain other psychological constructs (i.e., convergent and divergent validity), and perhaps most importantly, the ability to predict theoretically associated behaviors (e.g., perception of an autonomy supportive work climate predicting task engagement and performance). Hence, stakeholders (science, industry, farm) could anonymously complete a relevant questionnaire—perhaps with additional space for open-ended answers to allow for elaboration of important issues—to help project leaders longitudinally track a project's ability to satisfy (vs. thwart) partners' BPNs and intrinsically motivate them; a positive trend would theoretically predict project sustainability in the field once the research element comes to an end. Legumes researchers are directed to www.selfdeterminationtheory.org to further their understanding of SDT and the available measurement tools, and encouraged to discuss potential applications with motivation specialists.

Acceptability of Methodological Suggestions to Legumes Researchers and Their Partners

Adopting the SDT-implementation science approach corresponds to a minimal amount of additional project planning and execution. The cost-benefit ratio is favorable. If communicated effectively to project partners, the theoretical and practical rigor it adds to the participatory research agenda should stimulate their implicit buy-in. Of course it is also possible to *formally* evaluate their perceptions of acceptability, difficulty, complexity, and applicability. The need for feasibility and fidelity work is once again foregrounded: as previously explained, a feasibility study would assess stakeholder enthusiasm for the project and the probability of successful recruitment to it (including participant adherence and retention), predict associated risks and determine the safety of participants, and increase researcher experience with the intervention and process evaluation methods. By necessity the SDT-informed training and evaluation tools would be included in the feasibility study (sections Practical Tools to Harness Stakeholder Psychology and Measurement Tools to Help Legumes Researchers Assess Progress and Project Outcomes). Similarly, where intervention fidelity refers to the extent to which an intervention is delivered as intended (e.g., legume intercropping), an awareness of the requirements of a test of intervention fidelity allows legume researchers to maximize likelihood of this essential outcome (cf. Borrelli et al., 2005). Researchers are compelled to scrutinize their laboratory protocols, intervention training methods, and communication/dissemination strategies, and *fidelity* should be a logical consequence; as with project feasibility, the SDT-informed training and evaluation tools would comprise a component of this in-depth scrutiny.

The comprehensive SDT-implementation science participatory approach would essentially militarize all types of legumes research as a powerful weapon against the threat of climate change, food insecurity, and dwindling energy reserves (see **Table 1** for examples). The examples given to illustrate the suggestions made in this review have mostly focused on farmers, but are equally applicable to all stakeholders in global legume production. For example, researchers and their principal investigators—as well as their home research institution and associated funding bodies—can seek to create and contribute to a need-supportive and intrinsically motivating work climate (cf. Lam, 2011; Mamiseishvili and Rosser, 2011; Lechuga and Lechuga, 2012; Lyness et al., 2013; Biondi et al., 2015).

CONCLUDING STATEMENTS

The threat of climate change, food insecurity, and dwindling energy reserves are ever more pressing. Similarly, the challenges of achieving associated legumes research objectives are sizeable and complex (section Introduction: Global Challenges and **Table 1**). Multi-stakeholder collaborative and participatory approaches that account for (stakeholder) human factors, group dynamics, environmental and biological influences, as well as structural constraints and enablers, are urgently needed (cf. Payne et al., 2017). Hence, legume production in the global context will be advanced by participatory research methods that harness SDT principles and are underpinned by the rigorous planning and reporting standards advocated by implementation science. Specifically, this integrated approach can help us to address *what works*, *for whom*, *under what circumstances*, and collectively, help researchers to design interventions that

TABLE 1 | Examples of legumes research challenges that would benefit from the suggested approach.

Legumes challenge	References
Understand, predict, and intervene in how stakeholders will adapt to (expected) substantive shifts in the utilization patterns and price structure of grain legumes	Nedumaran et al., 2015
Support farmers in devoting more arable crop land to diversified crop rotations that include grain legumes, and overcome supply chain barriers and reliance on imported gain legumes	Lüscher et al., 2014; Nedumaran et al., 2015; Stagnari et al., 2017; Watson et al., 2017
Help farmers to manage competing production pressures which tends to see grain legumes pushed to areas of low rainfall and poor soil fertility	Nedumaran et al., 2015
Facilitate collaboration between scientists and farmers to combat grain legumes' yield variability and susceptibility to biotic and abiotic stresses	Nedumaran et al., 2015
Support farmers, extension workers, and scientists to work together to better utilize locally grown, less commercially demanded varieties of legumes that will be affordable for low-income consumers	Maphosa and Jideani, 2017
Test further hypotheses based on Bezner Kerr et al.'s (2010) results which suggest that improved nutritional health of farmers can be associated with growing legumes, but that this outcomes depends on many mediating and moderating variables (e.g., women empowered as agents of improved nutrition outcomes, local contexts taken into account, and small producers provided with support to capitalize on changing market demand for delivering agricultural and nutritional improvements)	Hawkes and Ruel, 2008; Bezner Kerr et al., 2010
Allow for a solution-focused debate about the sustainability of land, water and fertilizer use to produce first generation biomass feedstocks for non-food purposes	Biswas et al., 2011
Understand the self-determination challenges farmers' voice regarding the growth of perennial legumes in nutritionally depleted and stressed soils for use as biomaterial and in biodiesel/biofuel feed stock production	Biswas et al., 2011; Jensen et al., 2012
Work collaboratively with stakeholders to reduce variable and low yields, poor seed availability, lack of market, and raise awareness of indigenous legumes and their convenient food applications	Philips, 1993; Mtambanengwe and Mapfumo, 2009; Mhango et al., 2012
Help farmers reconcile their often competing motives for adopting certain practices under the reformed Common Agricultural Policy; and provide a methodology to overcome the further specialization in Europe of cropping systems which marginalize mixed legume farming systems and the benefits they can deliver	Stagnari et al., 2017; Watson et al., 2017
Facilitate collaboration between stakeholders to develop more adapted legumes systems at the local level, specifically in the following areas: (i) more predictable and controllable proportions of legumes within mixed plant communities, which, most probably, is achievable through innovative management strategies, optimized seed mixtures and breeding for increased competitive ability and/or niche complementarity; (ii) improved nutritive value of fresh forage and, especially, silage, which can be addressed by optimizing the energy/protein balance within the plants (e.g., by increasing water-soluble carbohydrate concentration); (iii) better exploitation of the multiple opportunities offered by plant secondary metabolites, which requires knowledge of optimum structures and concentrations of these compounds and development of cultivars and cultivation techniques that enable farmers to produce these optimized plant secondary metabolites reliably; and (iv) evaluation of impact of new systems on digestibility for livestock	Lüscher et al., 2014

can be "adapted and scaled up in ways that are accessible and equitable." Pathways to impact are created, utilized, and ultimately streamlined *throughout* each research project because stakeholders are actively involved from the genesis of the research question. Researchers come to embed stakeholder motives and motivation in all aspects of their project by employing SDT as a guiding framework. This, in turn, helps stakeholders to internalize the behaviors that are incumbent on them to enact if the implementation is to be beneficial and sustainable. While the focus of this review is legumes production, the guidance is equally applicable to other crops and agricultural systems.

AUTHOR CONTRIBUTIONS

SP conceived of the premise of the manuscript, wrote the SDT and implementation science sections, matched the legumes challenges to these approaches, and acted as overall editor of the work. PN-D wrote the legumes-specific content (state-of-knowledge and associated challenges) and provided feedback on SP and RH's sections. RH wrote the participatory research content and participated in discussions whilst the team finalized the premise of the manuscript and its structure.

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