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Counting the beans: quantifying the adoption of improved mungbean varieties in South Asia and Myanmar

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Abstract

The adoption of improved varieties is an important indicator of the effectiveness of agricultural research. This study quantified the adoption of improved mungbean (*Vigna radiata* (L). Wilczek) varieties and agricultural practices in Bangladesh, India, Myanmar and Pakistan using an expert elicitation approach. Data were collected from 19 expert panels, organized at subnational levels and involving a total of 259 mungbean experts. The study found that improved varieties were planted on 94% of the mungbean area in Pakistan, 89% in Myanmar, 82% in India and 72% in Bangladesh. International mungbean breeding research conducted by the World Vegetable Center has had a major impact with its germplasm adopted by an estimated 1.2 million mungbean farmers and grown on 1.8 million hectares of land. Widespread variation in the adoption of improved technologies at subnational levels point to opportunities for increased mungbean yields such as the adoption of line sowing and mechanical harvesting, the use of seed treatments with biofertilizers and biopesticides, and the adoption of better varieties with more comprehensive disease resistance.

Keywords Expert elicitation · Impact · Plant breeding · South Asia · Technology adoption

1 Introduction

Mungbean (*Vigna radiata* (L). Wilczek) is a grain legume common to South and Southeast Asia. The crop is popular among farmers as it fits well into the regions' rice-based farming system because of its short duration, low fertilizer requirement, and good performance under heat and drought stresses (HanumanthaRao et al. 2016; Bisht et al. 1998). Mungbeans are also protein- and iron-rich legumes that make an important addition to the cereal-based diets of poor people in South Asia (Nair et al. 2013).

Despite its importance to food and nutrition security, there is a lack of data on the use of improved mungbean varieties and other technologies in South Asia and Myanmar, which hinders strategic investment by governments and international donors. India, Bangladesh, Pakistan and Myanmar planted mungbean on 5.4 million hectares in 2015–2016 (Table 1). India had the largest area, but also the lowest average crop yield (0.4 tons/ha as compared to 1.3 tons/ha in Myanmar), which suggests wide variation in growing conditions and the use of technologies.

The objective of this study is to obtain a systematic overview of mungbean production in Bangladesh, India, Myanmar and Pakistan in terms of the use of improved varieties and agricultural practices such as line sowing (as opposed to broadcasting seed), seed treatment, mechanization, and grain storage. Another aim of the study is to deepen our understanding of the role and impact of international mungbean breeding

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Table 1 Basic data about mungbean production for the four countries studied, 2015–2016

	Bangladesh	India	Myanmar	Pakistan	Total
Area planted (1000 ha)	175	3828	1209	179	5392
Production (1000 tons)	181	1600	1597	99	3476
Average yield (kg/ha)	1030	420	1320	730	651
Farmers producing (1000 s)	151	2734	637	203	3687

Area and production data obtained from: Bangladesh Bureau of Statistics (2015); India: Directorate of Economics and Statistics (2017); Myanmar: Ministry of Agriculture, Livestock and Irrigation (2016); Pakistan: Ministry of National Food Security and Research (2017). Numbers of farmers calculated from the average mungbean area per farmer as reported by Miah et al. 2004; Schreinemachers et al. 2015; Schreinemachers et al. 2017; in Myanmar the number was calculated as the weighted average over the five subnational locations using average mungbean areas per farmer from various unpublished data sources. There is a high level of uncertainty about the actual number of mungbean farmers per country

in the region. These objectives were reached through expert elicitation panels organized in 19 major mungbean production areas in the region.

The importance of the study is that it shows extensive impact of international mungbean breeding and a culture of widespread collaboration and germplasm sharing among national agricultural research systems (NARS). The results also reveal gaps in the adoption of improved varieties and agricultural practices for some locations, which could guide future investment in research and extension. Furthermore, the study makes an important contribution to the method of expert elicitation by widening the scope of such studies from a narrow focus on improved varieties to a broader range of complementary innovations.

2 Materials and methods

2.1 Mungbean improvement in Asia

Mungbean improvement research is conducted by national agricultural research systems in Bangladesh, India, Myanmar and Pakistan and in other Asian countries such as China, Thailand, Vietnam, and the Philippines as well as in Australia. Mungbean has also been a mandate crop of the World Vegetable Center (WorldVeg) for over 40 years. The Center's genebank holds 14,187 genebank accessions of mungbean (the genebank's second largest collection after soybean) and has shared accessions and breeding lines with mungbean breeders worldwide (Schreinemachers et al. 2014).

International collaboration has always been a key feature of the various mungbean improvement programs in Asia and the World Vegetable Center has played an important role in connecting national programs, sharing germplasm, and testing advanced breeding lines in different countries. Early success was achieved in the early 1980s when researchers crossed climate-resilient and disease-resistant (powdery mildew and *Cercospora* leaf spot) lines from India with high yielding, early maturing and uniform maturing lines from the Philippines. These crosses were tested in international mungbean trials and two lines were identified as particularly promising (VC1973A and VC2778A), which were released as KPS1 and KPS2 in Thailand and became dominant mungbean varieties in Thailand, China (released as Zhong Lu #1 and E Lu #2, respectively), and several other countries (Shanmugasundaram et al. 2009).

During the 1990s, the focus of the WorldVeg mungbean breeding program expanded to include resistance to mungbean yellow mosaic disease (MYMD), which had become the major constraint to mungbean production in large parts of South Asia and Myanmar, though not in other parts of Southeast Asia. As part of a shuttle breeding program between Thailand and Pakistan that was financially supported by the UK government, the Nuclear Institute for Agriculture and Biology (NIAB) in Pakistan was the first to report MYMD resistance, which they had obtained through the irradiation (mutation breeding) of a local variety. NIAB and the World Vegetable Center collaborated to cross these resistant lines with KPS1, which after several generations led to two advanced MYMD-resistant lines: NM92 (standing for NIAB Mungbean 1992) and NM94. WorldVeg then introduced these lines to other countries in South Asia and promoted them to farmers. The main scaling method was seed multiplication of elite lines through the establishment of seed villages, wherein farmers produced their own seed and shared it with others (Shanmugasundaram et al. 2009).

Several impact studies were conducted in the mid-1990s when the success of improved mungbean varieties became clear. Ali et al. (1997) surveyed three major mungbean producing districts of Punjab province of Pakistan and found that 90% had adopted improved mungbean varieties, with NM92 adopted by 51% of farmers. The improved varieties had 55% higher crop yield and the economic benefit was estimated to be US$ 20 million per year. Weinberger (2005) studied the potential impact of increased mungbean yield on iron consumption and female worker productivity in Pakistan and showed that the improved mungbean varieties made an important contribution to economic development. Further

evidence of the nutritional benefit of mungbean consumption was reported by Vijayalakshmi et al. (2003) for India. For Bangladesh, Hossain et al. (2003) found that the area under BARI Mung-2 increased from 3% of the sown area in 1988 to 35% in 1998. Their study estimated that mungbean research and extension gave an internal rate of return of 34%. More recently, Haque et al. (2014) studied the adoption of improved mungbean varieties in Jessore, Kushtia and Barisal districts and found that NM92 (locally known as BARI Mung-5) and BARI Mung-4 were the most popular varieties, used by 49% and 24% of farmers, respectively.

Despite evidence for adoption and impact in the mid-1990s and early 2000s, there is little information about the adoption rates at national levels. It is largely unknown to what extent NM92 and NM94 have been replaced by more recent varieties and what role international mungbean breeding has played in these. Earlier studies were not nationally representative and focused on areas favorable to mungbean production, which may have overestimated the adoption of improved varieties.

2.2 Use of expert elicitation

The adoption of improved technologies is a key indicator for the economic impact of agricultural research. Tracking adoption rates over time requires a straightforward and inexpensive method that can be regularly repeated. Farm surveys are not very suitable to do this when farmers recycle their seed or rely on informal seed systems (Maredia et al. 2016), as many mungbean farmers do. Recent studies have collected plant or grain samples and applied DNA analysis to compare cultivated populations against a DNA library of released varieties (e.g. Floro et al. 2018; Rabbi et al. 2015; Yigezu et al. 2019; Wossen et al.2018). Such a method is scientifically robust, but costly to apply on a regular basis at a sub-continental scale.

The project "Diffusion and Impact of Improved Varieties in Africa (DIIVA)" (2010–2013) made an important contribution to the methods for quantifying adoption rates of improved varieties (Walker and Alwang 2015). The project covered 20 food crops and 30 countries using expert elicitation. Expert elicitation is a systematic method using repetitive and independent questioning of a panel of expert informants and is based on the Delphi method (Dalkey and Helmer 1963). The essence of the Delphi method is that a panel of experts answers questionnaires in two or more rounds with results summarized after each round and the panel revising its answers based on the anonymized estimates and judgments of the other experts.

Several previous studies have applied expert elicitation to quantify variety-specific adoption rates. For instance, Rashid and Hossain (2016) used the method to quantify the adoption of improved wheat varieties in Bangladesh, Shah et al. (2015) used it on wheat, chickpea, maize and rice in Pakistan, Tsusaka et al. (2015) applied it to improved rice varieties in

Bangladesh, Bhutan, India, Nepal, and Sri Lanka, and Ochieng et al. (2019) used it on improved amaranth varieties in Kenya and Tanzania. Comparing expert elicitation results with those of farm household surveys, Tsusaka et al. (2015) showed that expert elicitation provides close estimates of the area planted to modern varieties with estimates being more accurate when data are collected from subnational units and then aggregated to obtain a national estimate. They also noted that having enough experts with knowledge about varieties and a variety turnover rate that is not too high are important preconditions for successfully applying the method (Tsusaka et al. 2015). Both conditions were confidently met in this study.

Previous applications had a rather narrow focus on the adoption of improved varieties, which is a drawback because improved varieties are often adopted in combination with other technologies. Our study therefore expanded the method to include the following agronomic practices of relevance to mungbean: (a) seed treatment methods; (b) agronomic practices including line sowing and use of mineral fertilizers, chemical pesticides and irrigation; (c) use of mechanization for plowing, sowing, weeding, harvesting and threshing; and (d) control of bruchid beetles (*Callosobruchus sp.*) in stored mungbean grains through various methods (phosphine tablets, insecticide sprays, use of botanicals or use of hermetic storage bags).

2.3 Procedure applied

The study closely followed the expert elicitation guidelines as documented by the DIIVA project (Maredia and Reyes 2014). We defined an improved variety as "a variety developed by breeders in the formal system. It represents an output or contribution of the national and/or international public and private sector research systems" (Maredia and Reyes 2014: 3). The study conducted the following eight steps to collect and verify data:

1. A general study protocol and data entry form were developed for all countries to ensure data consistency across locations.
2. Secondary data on mungbean production and planting area were collected for each country at disaggregate levels (e.g. province or district) and used to identify 4–5 locations with the largest mungbean area per country, as shown in Fig. 1.
3. Experts (5–20 persons) were identified for each location and generally included agricultural researchers, extension officers, seed dealers, NGO staff, representatives of farm organizations, seed companies, and state seed corporations.
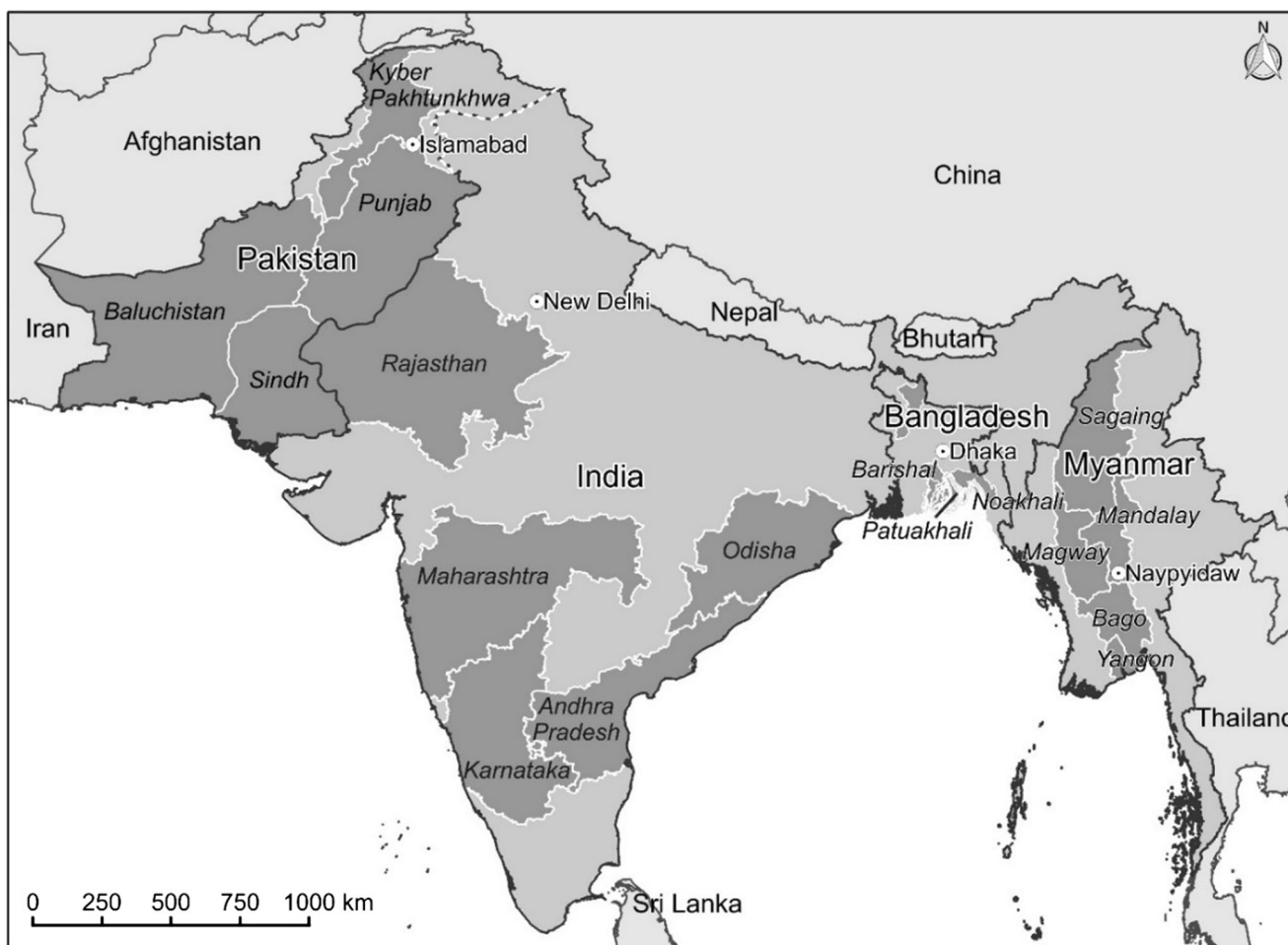
Fig. 1 Map of the four study countries showing the subnational units included

4. Invitations were sent to each expert describing the purpose and the importance of the study and asking them to complete the first-round questionnaire form and to bring it to the meeting. The questionnaires were in English, except for Myanmar where the questionnaire was in Burmese.

5. Expert panel meetings were convened locally in each region, except for Pakistan where the experts were invited to a single one-day meeting in the capital and regional estimates were made in parallel groups. The facilitator explained the purpose and the importance of the study and the procedure to be used. Experts put their estimates of adoption rates on cards and pinned them on a board. After all experts had revealed their estimates a facilitated discussion followed in which participants were encouraged to revisit their initial responses and reach consensus. Participants jointly filled out a second questionnaire at the end.

6. A final estimate for each location and each country was made and documented in a report, which was shared with selected key informants for feedback. The researchers followed-up by phone and the country reports were finalized after all feedback had been received.

7. For each variety identified through this process, additional data were collected about the year of release, the institutional source, varietal traits, the role of NARS and the role of the World Vegetable Center. All data were collected between June and December 2017.

8. The number of farmers adopting improved mungbean varieties was estimated as the planted area under improved mungbean varieties divided by the average planted area per mungbean farmer. Country averages were calculated by applying area-based weights to the consensus estimates per location. Similarly, an average over all countries was calculated using national mungbean areas as weights.

The data generated and analyzed during the current study are available from the corresponding author on request.

3 Results

This study covered 100% of the mungbean production areas in Pakistan, 99% in Bangladesh, 88% of the area in Myanmar,

and 68% of the area in India. Overall, the study covered 75% of the regions' total mungbean area of 5.4 million hectares.

3.1 Varietal adoption

Of the surveyed mungbean area across the region, 84% was planted to improved varieties (Table 2). Improved varieties were planted on 94% of the mungbean area in Pakistan, 89% in Myanmar, 82% in India, and 72% in Bangladesh. However, there were important subnational variations (see Annex Table 5). For India, the adoption of improved varieties in Odisha state was only 20% while it was 95% for Andhra Pradesh and 90% for Rajasthan (the largest mungbean growing state). In Bangladesh, the adoption of improved varieties was relatively low in Noakhali region (45%), but 72% for Patuakhali, which is the largest producer. In Myanmar, the adoption of improved varieties was 84% in the Central Dry Zone (Magway, Mandalay and Sagaing), but 99% in the delta region (Yangon and Bago).

Our study recorded a total of 53 improved mungbean varieties currently grown by farmers in the four countries with 28 cultivated varieties recorded for India, which reflects the fact that many Indian states have their own mungbean breeding programs. Annex Table 6 lists the top-10 mungbean varieties per country. The two most popular varieties in each country were found to contain germplasm that originated from the World Vegetable Center. In total, there were 19 currently used varieties that contained such germplasm (3 in India, 5 in Myanmar, 5 in Pakistan, and 6 in Bangladesh).

In Pakistan, 93% of the mungbean area was planted to varieties that contained genetic material developed at the World Vegetable Center (Table 2). This was 77% in Myanmar, 67% in Bangladesh and 27% in India. There are an estimated 0.50 million mungbean farmers in India

benefitting from WorldVeg material and a further 0.43 million in Myanmar. In total, it is estimated that WorldVeg material was planted on 1.8 million hectares and reached 1.2 million mungbean farmers.

The success of the WorldVeg international mungbean breeding program in reaching farmers is largely the result of the advanced breeding lines NM92 and NM94, which were the first sources of MYMD-resistance and were jointly developed by WorldVeg and NIAB in Pakistan. NM94 is the most popular mungbean variety in Bangladesh (where it is known as BARI Mung-6) and Myanmar (known as Yezin-11) and the second-most popular variety in India (SML 668) where it is grown in Odisha (8% of planted area) and Rajasthan (15%). In Pakistan, AZRI-06 currently dominates, which has NM92 as one of its parents. Overall, NM92 and NM94-related material was planted on 21% of the mungbean area across the four countries studied.

3.2 Adoption of agricultural practices

The use of certified seed was found to be low in all four countries, reflecting farmers' practice of recycling seed from their own grain harvest and purchasing seed from the open grain market. On average, farmers bought new seed every 3 cropping cycles (Table 3). In Myanmar, the use of certified seed was more common in the Central Dry Zone (36% of seed) than in the delta region (1%). However, further probing of local experts showed that the term 'certified seed' may have been misunderstood as simply meaning 'quality seed' and some experts thought that the actual number for the Central Dry Zone should be closer to 3%. In India, the use of certified seed was higher in Andhra Pradesh (58%) than in the other states and particularly low in Odisha (15%) and Rajasthan (12%). For India, experts mentioned that in addition to

Table 2 Use of improved varieties and role of the World Vegetable Center, 2016–2017

	Bangladesh	India	Myanmar	Pakistan	Total
All improved varieties:					
- Number of varieties	9	28	9	7	53
- Share in total area planted (%)	72	82	89	94	84
- Area planted (1000 ha)	125	2144	948	169	4026
- Farmers using (1000s)	108	1531	499	192	2782
WorldVeg-related varieties:					
- Number of varieties	6	3	5	5	19
- Share in total area planted (%)	67	27	77	93	45
- Area planted (1000 ha)	117	697	822	166	1802
- Farmers using (1000s)	101	498	433	189	1245

Data for India and Myanmar refer to the subnational units covered by this study (68% of total area for India, 88% for Myanmar), while data for Pakistan and Bangladesh cover 100% of these countries' mungbean area. The actual area planted under improved varieties and the number of farmers using these will therefore be higher for India and Myanmar

Table 3 Use of agronomic practices in mungbean production, in percent of farmers, 2016–2017

Agronomic practice	Bangladesh	India	Myanmar	Pakistan	Total
Use of certified seed (% of seed)	18	18	23	12	19
Average varietal age (years)	16	15	13	9	14
Seed replacement rate (cropping cycles)	2	3	4	3	3
Seed treatment with:					
- Insecticides	0	30	26	0	27
- Fungicides	1	38	29	2	33
- Biopesticides (e.g. Trichoderma)	0	10	0	0	7
- Biofertilizers (e.g. Rhizobium)	0	14	2	1	10
Line sowing	3	82	48	59	71
Irrigation (times)	0.1	0.4	1.6	2.8	0.8
Mineral fertilizers, basal dressing	52	57	62	37	57
Mineral fertilizers, top dressing	12	3	33	0	10
Mineral fertilizers, foliar	0	3	99	31	25
Chemical insecticides/fungicides	87	50	97	94	63
Herbicides (defoliator)	0	2	0	1	1
Use of mechanization for:					
- Land preparation	96	91	83	100	89
- Sowing	1	74	0	58	55
- Weeding	0	4	0	20	4
- Harvesting	0	14	0	1	10
- Threshing	0	83	82	96	80

certified seed there is Truthful Seed (TFS), which was not captured in the questionnaire, but its use was reported as common in Maharashtra and Karnataka.

The average age of varieties used by farmers ranged from 9 years in Pakistan to 16 years in Bangladesh. This points to the fact that open-pollinated varieties scaled through public sector seed systems are slow to diffuse. In comparison, Tsusaka et al. (2015) also found that it takes more than a decade for farmers in South Asia to adopt a new rice variety after its release.

Seed treatment with insecticides and fungicides can be an effective method to deal with certain pests such as white fly—a vector for MYMD, and for control of seed-borne and root rot pathogens. Not many farmers use such seed treatment with the exceptions of Rajasthan (India) and Magway (Myanmar) where 50% of farmers use either insecticides or fungicides to treat seed. The adoption of fungicide seed treatment is high in Andhra Pradesh (90%) and Karnataka (45%) in India. Further, in India (all states except Odisha), about 10% of the growers use biopesticides such as *Trichoderma* for seed treatment. However, seed treatment with chemical or biological pesticides is rarely done in Pakistan and Bangladesh, although the majority of farmers do spray chemical pesticides at later stages of the crop. Finally, seed treatment with biofertilizers such as Rhizobium can promote nodulation and plant growth. This is practiced in Karnataka (10% of farmers), Rajasthan

(20%) and Mandalay (10%), but adoption levels are near zero anywhere else.

Mungbean production is mechanized to varying degrees. Land preparation is nowadays done by tractor nearly everywhere and also threshing of bean pods is mostly done mechanically, except in Bangladesh and Odisha, India where all mungbean is still threshed by hand. Sowing is largely mechanized in Pakistan and India, but not in the other countries. Machine weeding is used in Punjab's Thal region (25% of farmers) and in India's Rajasthan (8%) but is absent anywhere else. Machine harvesting using combine harvesters was found to be relatively common in Andhra Pradesh (70% of farmers), Karnataka (25%) and Rajasthan (15%), but this is rare elsewhere. In general, mungbean production in Bangladesh is the least mechanized while it is most mechanized in India and Pakistan.

The use of mineral fertilizers and chemical pesticides is widespread in Myanmar, particularly in the Central Dry Zone. Fertilizers are most commonly applied at the time of sowing (i.e. basal dressing), which saves labor time. Foliar application of mineral fertilizers in liquid form is common in Andhra Pradesh (75% of farmers), all regions of Myanmar (>90%), and Punjab's Thal region (40%), but not elsewhere. The use of chemical pesticides was common nearly everywhere. Desiccants (i.e. herbicides) can also be used in mechanical mungbean production to kill the plant and stimulate ripening, but our study shows that adoption rates are close to zero.

Bruchid beetles are the main pests in stored mungbean. Infestation often happens in the field, but the beetles can rapidly multiply in storage, particularly under humid conditions. In Pakistan, 70% of the farmers use phosphine tablets, but virtually no other method (Table 4). In Bangladesh and Myanmar, about 28% use phosphine tables and 20–35% use botanicals. Common botanicals include neem leaves, neem oil and castor oil. In Myanmar these methods are used by the storage agents as farmers do not store mungbean on their farms. In India, the use of any control methods is generally low, but some experts said that farmers sprinkle ash or sand in the storage bins, which was not captured in the questionnaire. Hermetic storage bags are not used for mungbean in any country; its use may be more common in rice. The use of chemical insecticides and fungicides in stored mungbean was uncommon, which may indicate that farmers are aware of its health risks if the beans are used for human consumption.

4 Discussion

4.1 Summary of key results

Mungbean is an important crop in Bangladesh, India, Myanmar and Pakistan with a total planted area of 5.4 million hectares and 3.7 million smallholder farmers involved (2015–2016). This study covered about 75% of this area and found that improved mungbean varieties were planted on 84% of it with local or traditional varieties occupying the remaining 16%. The use of improved varieties was low in some locations such as Odisha in India (20%), Noakhali in Bangladesh (45%), and Sindh & Baluchistan in Pakistan (25%).

World Vegetable Center contributed to the success of improved mungbean varieties by connecting the national mungbean breeding programs across Asia, crossing lines with desirable traits from different locations, introducing the best performing ones into new locations, supporting quality seed supplies, and promoting farm-level

adoption. Intensive collaboration with the national programs has been a key factor behind the success. As a result, this study found that 93% of the mungbean area in Pakistan, 77% in Myanmar, 67% in Bangladesh, and 27% in India are planted to varieties that contain improved germplasm developed by the World Vegetable Center in partnership with national systems.

In India, only 3 out of 28 cultivated varieties were related to WorldVeg. A possible explanation is that many states in India have their own mungbean breeding program and each promotes its own varieties. The other countries have fewer programs, which makes collaboration easier. Therefore, to better assist farmers in India, the World Vegetable Center will need to try and collaborate better with state-level mungbean programs. These programs should have a strong interest in collaboration because, of the 30 improved varieties identified in this study for India, only 51% had resistance against MYMD, 24% had powdery mildew resistance, and 10% had Cercospora leaf spot resistance, which are the three most important mungbean diseases. The lack of these key traits in the varieties cultivated may help to explain the low crop yields in India as compared to the other countries.

For India and Myanmar, the actual number of farmers benefitting from the work of the World Vegetable Center may be higher than estimated because our study covered only 88% of the planted area in Myanmar and 68% for India. We selected the largest mungbean growing states for our study and these may not be representative for the other mungbean growing states. The estimates were therefore not extrapolated to the other states; doing this, would otherwise have increased the total number of farm households reached to 1.5 million.

4.2 Reflection on the use of expert elicitation

The adoption of improved agricultural technologies is an important indicator of the impact of agricultural research and this study showed that it is straightforward to quantify adoption rates using expert elicitation. A novelty of this study was to quantify not only the

Table 4 Control of bruchid beetles in stored mungbean, in % of farmers, 2016–2017

	Bangladesh	India	Myanmar	Pakistan	Total
Use of phosphine tablets	28	4	27	70	12
Insecticide/fungicide sprays	0	2	1	3	2
Botanicals	20	11	35	0	17
Hermetic storage bags	0	0	0	0	0

For Myanmar this refers to the % of storage agents (brokers, middlemen) as farmers do not store mungbean on their farm

adoption of improved varieties but also of other agricultural practices, which provides a more comprehensive overview of the status of technology adoption. However, whereas farmers can usually not tell the name of the variety they sow, it will be easier for them to tell the adoption of the other practices.

Low cost and the ability to cover large geographical areas are the main advantages of expert elicitation. Several of such studies have covered multiple countries (e.g. Tsusaka et al. 2015 covered five countries in South Asia and the DIIVA project covered 20 crops in 30 countries) while DNA fingerprinting studies are still limited to single-country or subnational pilot studies. The total cost of doing this study for four countries (including 19 expert meetings, subsequent data analysis and write-up) was about US$ 120,000, which may guide future studies. Another strength of the method is that the involvement of local experts in the estimation gives them ownership of the findings. This is important as it increases the likelihood that the study results would be used by the relevant public and private organizations to target extension efforts.

However, there are also disadvantages of using expert elicitation, the main ones being a potential low level of accuracy and an unknown confidence interval of the estimates. Tsusaka et al. (2015) found for rice in South Asia that expert panels provided estimates of adoption rates similar to those of farm household surveys, particularly for the dominant varieties. However, comparing expert elicitation with farm surveys and DNA fingerprinting in the case of lentil varieties in Bangladesh, Yigezu et al. (2019) showed that expert panels have a bias toward overestimating the adoption of later-released varieties while underestimating the adoption rate of older varieties. Other recent studies also show that varietal adoption rates estimated from farm surveys may not be accurate (Maredia et al. 2016; Wossen et al. 2018).

The use of DNA fingerprinting is therefore the preferred method of studying varietal adoption, and its large-scale application may become feasible in the future if the cost of genotyping continues to decline. Until then, expert elicitation methods remain useful to monitor the adoption of improved varieties and agronomic practices at a large-scale.

4.3 Future directions for international mungbean breeding

Since the 2010s, emphasis in the World Vegetable Center mungbean breeding program was placed on increasing the diversity of cultivated mungbean to reduce the dominance of NM94, which was found to be susceptible to the MYMV-urdbean strain prevalent in northern India (Nair et al. 2015,

2017). The Center developed a mungbean mini-core collection of 296 accessions, which gives breeders worldwide easier access to the existing genetic diversity of mungbean (Schafleitner et al. 2015). New sources of resistance (for example, ML1628) were identified, including from a related species (*Vigna mungo* L. Hepper) (Nair et al. 2017) and new lines were developed with resistance to all major strains of MYMV. In addition, the program developed lines with resistance to bruchids (Nair et al. 2015). WorldVeg leads an International Mungbean Improvement Network funded by the Australian Centre for International Agricultural Research (ACIAR), with partners from Bangladesh, India, Myanmar and Australia. Activities of this network include sharing of germplasm and new improved lines, implementation of an integrated breeding platform, and capacity building.

5 Conclusions

Improved mungbean varieties are widely adopted by farmers in Bangladesh, India, Myanmar and Pakistan. International mungbean breeding research, as conducted by the World Vegetable Center in partnership with national mungbean programs, has made an important contribution to the spread of these improved varieties and benefits about 1.2 million farm households. However, further efforts are needed to promote improved varieties with more comprehensive resistance against the main pests and diseases as well as abiotic stresses such as heat, drought and salinity. There are also clear opportunities to increase mungbean yields in particular locations through the promotion of good agricultural practices such as the use of certified seed, seed treatment, line sowing, and good storage practices while the adoption of mechanization in various stages of production (sowing, weeding, harvesting, and threshing) can improve profits where the cost of farm labor is high.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Annex 1

Table 5 Adoption of improved mungbean varieties by country and subnational unit, 2016–2017

Country / Subnational location	Expert informants (persons)	Planted area (ha)	Grain yield (kg/ha)	Improved varieties (% area)	WorldVeg-related varieties		
					# varieties	% area adopted	# farmers reached (1000)[a]
Bangladesh	80	175	1030	72	6	67	101
- Barisal	20	40	1118	80	4	70	24
- Noakhali	20	15	631	45	3	44	6
- Patuakhali	20	118	1051	72	4	69	70
- Rangpur	20	1	714	85	3	71	0
India	87	3828	418	82	3	27	498
- Andhra Pradesh	16	212	646	95	1	5	8
- Karnataka	19	357	157	85	1	2	5
- Maharashtra	25	385	187	90	0	0	0
- Odisha	11	285	294	20	3	12	24
- Rajasthan	16	1373	439	90	3	47	461
Myanmar	67	1209	1320	89	5	77	406
- Bago	15	231	863	99	5	79	90
- Magway	12	313	1351	80	4	72	111
- Mandalay	12	136	573	81	2	80	54
- Sagaing	14	230	1048	90	2	90	103
- Yangon	14	151	1380	100	3	65	49
Pakistan	25	179	728	94	2	30	61
- Khyber Pakhtunkhwa	3	12	612	90	0	0	0
- Punjab (Pothwar)	7	5	304	99	1	35	2
- Punjab (Thal)	6	139	752	98	2	29	46
- Punjab (other)	4	15	567	99	2	77	13
- Sindh & Baluchistan	5	8	1035	25	1	2	0

Planted area and grain yield based on national statistics for 2015–2016 (see Table 1 for sources). Adoption of improved varieties at the national level calculated as the average of the subnational estimates weighted by planted area

[a] Calculated over the subnational locations that were surveyed, conservatively assuming zero adoption in all other areas

Table 6 Top-10 improved mungbean varieties per country, in % of area planted, 2016–2017

	Bangladesh			India		
	Variety	Year	%	Variety	Year	%
1	BARI Mung-6 *	2003	48	IPM 2–3 *	2009	16
2	BARI Mung-5 *	1997	10	SML 668 *	2002	9
3	BARI Mung-2 *	1987	7	Other varieties	–	7
4	Binamoog-5 *	1998	2	GM 4	2003	6
5	Binamoog-8	2010	2	NUL 7	2009	5
6	BARI Mung-3	1996	1	LGG 460	1997	4
7	Other varieties	–	1	Utkarsha	2016	4
8	Binamoog-6 *	2005	<1	RMG 492	2003	4
9	BARI Mung-4 *	1996	<1	China mung	1975	4
10	Binamoog-7	2005	<1	Shiny mung	1975	3

	Myanmar			Pakistan		
	Variety	Year	%	Variety	Year	%
1	Yezin 11 *	2007	39	AZRI 06 *	2006	59
2	Yezin 14 *	2011	26	NM 11 *	2011	29
3	Yezin 1	1976	9	Inqilab Mung *	2013	3
4	Yezin 9 *	2003	7	Sono Mung *	2015	<1
5	MAS 1 *	2009	5	AEM96	1997	<1
6	Mya Kya Mon	1975	1	NM 16 *	2016	<1
7	Zotkalay	1988	<1	Dera Mung-2009	2009	<1
8	Yezin 6 *	1993	<1	Other varieties	–	<1
9	Yezin 4	1987	<1	–		
10	–			–		

In % of area planted for the surveyed locations

* Variety with WorldVeg-developed genetic material in its pedigree

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