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Mungbean in Southeast Asia and East Africa: varieties, practices and constraints

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Abstract

Background: Improving the productivity of grain legumes is important to address global challenges of food security and soil degradation. This study's objective was to quantify the adoption of improved mungbean (*Vigna radiata* L.) varieties and agricultural practices and to identify production constraints for six countries in Southeast Asia and three countries in East Africa.

Methods: A Delphi method using expert elicitation was applied at subnational levels and then aggregated to national levels. Each panel employed repetitive and independent questioning of experts. The study organized 31 expert panels involving 387 experts across 9 countries.

Results: The share of improved varieties in the planted area, as estimated by the expert panels, was 92% for the Philippines, 91% for Vietnam, 99% for Thailand, 84% for Cambodia, 60% for Indonesia, 35% for Laos, 91% for Kenya, 30% for Uganda and 25% for Tanzania. The average age of improved varieties was 19 years in Asia and 12 years in East Africa. Of the mungbean area in Southeast Asia, 61% was planted to varieties developed by the World Vegetable Center, but this was only 2% in East Africa. Production constraints generally included insect pests and plant diseases, unstable markets with low price and low market demand, and the lack of quality seed of suitable varieties.

Conclusions: There are ample opportunities to improve mungbean productivity through wider use of improved varieties and practices, which is important to meet the contemporary challenges of improving human nutrition and agricultural sustainability.

Keywords: Expert elicitation, Technology adoption, Legume, Improved varieties, Innovation

Background

There is a need to transform global food systems to align these better with the objectives of human health and environmental sustainability [1–4]. The EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems concluded that the global consumption of fruit, vegetables, nuts and legumes will have to double by 2050, and the consumption of unhealthy foods such as red meat and sugar will have to be reduced by more than 50% [2]. Legumes play an important role in this global food system transformation because they provide a plant-based source of dietary proteins and other essential micronutrients. Furthermore, the ability of legumes to fix nitrogen from the atmosphere is important to agricultural sustainability [5].

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Yet, many grain legumes have a low yield relative to other crops, and yield increases have also not kept pace with that of cereals and oil crops [6–8]. Most grain legumes have not been a focus of plant breeding research and have been neglected in agricultural policy. Investments in plant breeding research of nutrient-sensitive crops such as legumes is therefore important for human health and environmental sustainability [9], but guiding this investment and monitoring progress requires better information about the current situation in legume production.

Soybean, groundnut, common bean, cowpea and mungbean are the major grain legumes cultivated in Southeast Asia and East Africa. This study focuses on mungbean (*Vigna radiata* (L.) R. Wilczek var. *radiata*), which is an underutilized crop not separately listed in the statistical database of the Food and Agriculture Organization (FAO), yet recognized as a "future smart food" for Asia [10]. In East and Southeast Asia, mungbean is commonly used to produce bean sprouts as well as to produce transparent noodles and mungbean paste, while in East Africa, it is more commonly consumed as a bean stew [11]. The crop is of limited interest to the private seed sector, because there are no commercial hybrids and it is straightforward for farmers to save their own seed. Variety development and scaling therefore largely rely on the public sector.

This study's objective was to quantify the adoption of improved mungbean varieties and agricultural practices and to identify production constraints for six countries in Southeast Asia and three countries in East Africa. This is important to guide future mungbean research and development as there is a lack of systematic and nationally representative information about current varieties, agronomic practices, and the constraints to mungbean production. As shown in Table 1, the nine study countries planted mungbean on about 1.0 million hectares, producing about 0.77 million tons of dry grain, which is about 16% of global production [11]. An earlier study documented such data for Myanmar, India, Bangladesh and Pakistan [12], which account for 66% of global production. This study employed a Delphi method that relied on expert estimates with data collected in 9 countries, through 31 expert panels organized at sub-national levels, and involving 387 experts. For each country, the study selected the major production areas that accounted for about three quarters of the national mungbean area.

The study also quantified the adoption of improved varieties developed by national mungbean programs from improved germplasm supplied by the World Vegetable Center (WorldVeg), which has had an international mungbean breeding program since 1973. Until recently, this program had a strong focus on Asia, where mungbean is more important economically. The adoption of WorldVeg mungbean material in Africa was unknown.

Secondary data (not shown here) indicate that the total area under mungbean in Southeast Asia has declined by 100,000 ha (−18%) from 2008 to 2017. Indonesia accounted for most of this decline as its mungbean area decreased by about 25% [13]. A likely reason is that the profits from mungbean are lower than that of alternative crops. In contrast, the area under mungbean in East Africa appears to be increasing, although the available data show a strong year-on-year variation. In Asia, the average mungbean farmer planted about 0.5–1.0 ha, with a larger average area in Thailand (6.2 ha/farmer) and a smaller area in Vietnam (0.2 ha/farmer). In East Africa, the average area is 0.4–1.4 ha per producer.

Table 1 Mungbean production statistics for the nine countries included in this study, 2016–17

Region/country	Area planted (1000 ha)	Production (1000 t)	Average yield (t/ha)	Farm households producing (1000 s)
Southeast Asia				
Cambodia	45	54	1.18	40
Indonesia	207	244	1.18	492
Laos	2	3	NA	3
Philippines	42	35	0.84	51
Thailand	82	86	1.04	13
Vietnam	83	92	1.11	378
East Africa				
Uganda	42	33	0.72	61
Kenya	302	149	0.49	137
Tanzania	217	73	0.34	494

Area and production data obtained from [13–21]. Considering the mungbean production system in Laos, official yield and production data appeared unrealistic and are therefore not shown. The number of farm households producing mungbean was calculated using the average mungbean area per farmer as estimated by the expert panels

Materials and methods

Estimating varietal adoption

Farm household surveys, seed sales data, DNA fingerprinting and expert elicitation are common methods to quantify farm-level adoption of improved varieties. These methods vary in terms of data collection costs, accuracy, and the possibility to track varietal adoption over time. Farm household surveys are the most common method to study technology adoption [e.g. 22–24]. However, surveys are generally not suitable when farmers are unable to tell which crop varieties they use, which is usually the case when they use grain from the market rather than certified seed.

DNA fingerprinting is widely considered as the most accurate method for estimating the adoption of crop varieties [e.g. 25–29]. Previous studies have piloted the fingerprinting method at a sub-national level. Still, there have been no large-scale applications at a sub-continental scale or repeated studies over time, although this may become possible in the future as the cost of genotyping decreases.

The only realistic method to do this at this moment is the use of expert opinion. Expert elicitation is a systematic method that employs repetitive and independent questioning of a panel of experts to deal with a complex problem. This Delphi method [30] is generally used to synthesize opinions of experts on a subject in which there is uncertainty due to insufficient data [e.g. 31–33]. The method uses a heterogeneous group of experts, whose knowledge and expertise reflect the full scope of the problem domain, to estimate adoption levels in two or more rounds with results summarized after each round and the panel revising its responses until a consensus estimate is attained.

The application of the method to crop varietal adoption was piloted in the projects "Diffusion and Impact of Improved Varieties in Africa (DIIVA)" and "Tracking Improved Varieties in South Asia (TRIVSA)", which were implemented by the CGIAR and partners from 2010 to 2013. These projects made an important contribution to the development and testing of the method [34]. Subsequent studies have published findings on wheat varieties in Bangladesh [35], rice varieties in Bangladesh, Bhutan, India, Nepal, and Sri Lanka [36], amaranth varieties in Tanzania and Kenya [37], and mungbean in South Asia and Myanmar [12].

This study employs expert elicitation to estimate the adoption rates for improved mungbean varieties and for agronomic practices relevant to mungbean production. Production practices whose adoption was estimated include seed treatment methods, sowing practices, fertilizer and pesticide application, mechanization during ploughing, sowing, weeding, harvesting and threshing, and postharvest practices like the use of phosphine tablets, insecticide sprays, use of botanicals or use of hermetic storage bags to control bruchid beetles (*Callosobruchus* sp.) in stored mungbean grains. We note that higher adoption of these practices does not necessarily imply better management. Our purpose is to describe the use of certain practices without judgement. The study also identified key production constraints for each survey region to guide priority setting in mungbean research.

Expert elicitation method

This study followed existing guidelines for collecting varietal release and adoption data [36, 38]. Following Maredia and Reyes [38], an improved variety is defined 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". The following eight-step procedure was applied to collect and verify data.

1. A common study protocol and data entry form were developed for all countries to ensure consistency of data across locations.
2. Secondary data on mungbean production and planting area were collected for each country at sub-national levels (e.g. province, or region) and used to select locations for the expert panels. The study used 31 expert panels across 9 countries.
3. Panels of experts were identified for each location. It was tried to compose panels that are diverse in terms of knowledge and expertise and these generally included agricultural researchers, extension officers, seed dealers, NGO staff, and representatives of farm organizations, seed companies and state seed corporations.
4. Experts were invited to the expert panel meetings. The invitations described the purpose and the relevance of the study. Questionnaires were translated in the local language (except for the Philippines, Uganda and Kenya where an English questionnaire was used), and shared with the experts in advance of the meeting.
5. Expert panel meetings were convened locally in each region in Indonesia, Philippines, Laos, Kenya, Uganda and Tanzania whereas for Cambodia, Thailand and Vietnam experts were invited to a single 1-day meeting as some experts in these countries were part of several sub-national panels. The study involved a total of 387 experts. Tables 7 and 8 show the exact number of experts per panel meeting, which ranged from 7 to 15 in Asia and from 9 to 19 in Africa. Not every location had many mungbean experts and invited experts were not always able to

attend, which explains the variation in the meeting size. The facilitator explained the purpose and the importance of the study and the procedure to follow. Experts put their adoption estimates on cards and pinned them on a board. A facilitated discussion followed in which participants were encouraged to revisit their initial responses and reach consensus. A final estimate for each domain was made with participants jointly filling out the panel consensus questionnaire. Meetings were organized between March and May 2019.

6. For each variety identified through this process, additional data were collected about the year of release, the institutional source, varietal traits, the role of the National Agricultural Research Systems (NARS) and the source of germplasm.
7. Country averages were calculated by applying area-based weights to the consensus estimates per location. Regional averages were calculated using national mungbean areas as weights.

In Southeast Asia, the selected study locations covered 378,954 ha of the mungbean planted area (as based on the national statistics cited in Table 1), equivalent to 82% of the total area under mungbean (86% in Thailand, 86% in Laos, 84% in Indonesia, 82% in the Philippines, 80% in Vietnam, and 68% in Cambodia). In East Africa, the study locations covered 418,838 ha, which is 75% of the region's mungbean planted area (76% in Kenya, 71% in Tanzania and 82% in Uganda). The lower coverage in Cambodia and Tanzania is because mungbean is produced in many different parts of these countries, which could not all be covered by the study. We note that where mungbean is intercropped, the data generally refer to the total area under both crops.

Results

Varietal adoption

The expert elicitation identified 77 improved mungbean varieties in the six countries of Southeast Asia and 11 improved varieties in the three countries of East Africa (Table 2). The number of improved varieties is relatively high in Vietnam, Indonesia and the Philippines. Aggregating the results of the expert panels to the nation and regional level shows that improved mungbean varieties accounted for 78% of the mungbean area in Southeast Asia, ranging from 35% in Laos to 99% in Thailand. Experts estimated that the adoption of improved varieties in East Africa was 25% for Tanzania, 30% for Uganda, and 91% for Kenya.

In Thailand, Vietnam and Kenya, the share of improved varieties was high across all locations, but other countries showed strong sub-national variations (see Appendix: Tables 7, 8). For example, in Cambodia, the adoption of improved varieties was 67% in Central Cambodia but 85% in the Upper Zone of the country. Similarly, in Indonesia, the adoption of improved varieties was estimated to be 42% in Central Java, 64% in East Java, 80% in South Sulawesi, and 90% in West Nusa Tengara. Particularly, large differences were found in Laos, where improved varieties occupied 70% of the mungbean area in the North region, but 0% in the South and Central regions. In the Philippines, adoption of improved varieties was estimated to be near 100% for Ilocos and Central Luzon and Cagayan Valley, but only 55% in Western Visayas. In Uganda, the adoption of improved varieties was 40% in

Table 2 Adoption of improved mungbean varieties in Southeast Asia and East Africa, 2017–18

	Southeast Asia							East Africa			
	KHM	IDN	LAO	PHL	THA	VNM	Total	UGA	KEN	TZA	Total
All improved varieties											
# of varieties	12	21	2	15	5	22	77	5	4	2	11
% of area planted	84	60	35	92	99	91	78	30	91	25	61
Area planted (1000 ha)	26	106	0.6	32	70	61	295	35	229	133	418
Farmers using (1000 s)	23	250	0.9	38	11	277	601	50	104	353	507
WorldVeg-related varieties											
# of varieties	5	18	0	6	5	10	44	2	2	0	4
% of area planted	60	56	0	22	99	58	61	16	1	0	2
Area planted (1000 ha)	18	98	0	8	70	39	231	5	2	0	7
Farmers using (1000 s)	16	231	0	9	11	176	444	8	1	0	9

Data refer to the subnational units covered by this study: 68% of the planted area in Cambodia (KHM), 86% in Laos (LAO), 84% in Indonesia (IDN), 82% in Philippines (PHL), 86% in Thailand (THA), 80% in Vietnam (VNM), 76% in Kenya (KEN), 71% in Tanzania (TZA), and 82% in Uganda (UGA). The actual area planted under improved varieties and the number of farmers using these varieties will therefore be higher. Regional averages were calculated using mungbean areas as weights the Acholi region, 25% in Teso region and 30% in Lango and West Nile region.

The international mungbean breeding program of the World Vegetable Center (WorldVeg) was an important source of improved varieties in Southeast Asia, but not in East Africa. In Southeast Asia, 44 of the 77 improved varieties were related to this breeding program and accounted for 61% of the total mungbean area—although with much variation between countries as it was 0% for Laos, 22% for Philippines, but 99% for Thailand. Other varieties were developed by national breeding programs from their own germplasm collection or were introduced from other countries. However, in East Africa, the study only identified 4 (out of 11) improved mungbean varieties related to the WorldVeg breeding program and these accounted for 2% of the area planted. In total, we estimate that the WorldVeg mungbean program reached about 444,000 mungbean farmers in the study countries in Southeast Asia and 9000 in East Africa.

Table 3 lists the top-10 improved mungbean varieties per country. It was not always possible to determine the year of release, particularly for long-established varieties. In some countries such as the Philippines and Laos, it was also difficult to identify varieties by name as people identified mungbean varieties by a particular characteristic (e.g. "dark green") rather than a registered variety name. The data show that the average age of improved varieties was 19 years in Southeast Asia and 12 years in East Africa with the difference being indicative of the age of the respective mungbean programs.

Adoption of agricultural practices

The results of the expert panels show that the use of certified seed (that is, seed purchased new from formal sources) is relatively high in Vietnam (79%), Thailand (68%), Cambodia (62%) and Kenya (39%) as compared to the other countries (Table 4). In these other countries, it is more common for farmers to buy seed from the open grain market or recycle their own seed. The use of certified seed is particularly low in Indonesia (9% of farmers), Uganda (6%) and Tanzania (2%).

Seed treatment with chemical insecticides can be effective to deal with certain pests such as whitefly (a vector for mungbean yellow mosaic disease—the most important disease in mungbean production), and seed treatment with fungicides can control seed-borne and root rot pathogens. The expert estimates show that the use of seed treatment with insecticides is generally low in all the countries except Philippines (25%, mostly in Ilocos) and Thailand (15%, mostly in the lower northern region). Seed treatment with fungicides appears common only in Thailand (29%, again mostly in the lower northern region). Seed treatment with bioagents (e.g. Trichoderma) or biofertilizers (e.g. Rhizobium) can promote nodulation and plant growth, but this appears only common in the lower northern region of Thailand (Table 4).

Seed rates are generally higher where farmers sow by manual broadcasting rather than sowing in rows. This explains a relatively high seed rate for Thailand (68 kg/ha) where only 13% of farmers use row sowing as compared to 19 kg/ha in Vietnam were 76% of farmers sow in rows. Row sowing is also common in Kenya (86% of farmers), Indonesia (57%), Cambodia (52%) and Tanzania (45%). The exception is the Philippines where farmers use a relatively low seed rate (21 kg/ha) while 90% broadcast seed. Line sowing is also commonly practiced particularly where mungbean is intercropped.

Foliar application of mineral fertilizers is widespread in all countries in Southeast Asia, except for Laos. Fertilizer application on mungbean appears particularly common in Vietnam. The use of mineral fertilizers on mungbean production in East Africa appears generally low, but is more common in Kenya than in Uganda and Tanzania. Chemical insecticides and fungicides are used by the majority of mungbean farmers in all countries except Laos (4% of farmers using them). It is particularly common in Thailand (89%), Philippines (77%), Vietnam (77%), and Kenya (77%).

Some farmers use herbicides during land preparation to save labor costs as it reduces the need for soil tillage, though this practice may not be economical everywhere. The expert estimates show that this practice is common in Vietnam (74%), Indonesia (43%), and Cambodia (36%). It is less common in East Africa (11%), Philippines (2%) and Thailand (8%). Herbicides can also be used to desiccate leaves to enable machine harvesting, but such usage was only common in Cambodia (18%).

The use of mechanization in the production of mungbean varies much among countries. Land preparation by tractor is generally applied, except for Indonesia (31% of farmers), Laos (43%) and Tanzania (55%). Mechanized sowing is only widely practiced in Thailand (63%) and parts of Cambodia (mainly in the Upper Zone). Broadcasting seeds is practiced in Thailand by 87% of the farmers where the average farm size is large (6.2 ha/farmer). Thailand generally has a high degree of mechanization in mungbean production with 67% of farmers doing mechanical weeding, 95% doing machine harvesting, and 94% doing machine threshing. Machine threshing is also common in most other parts of Southeast Asia (except West Nusa Tenggara Barat in Indonesia and in the South of Laos), but is rare in East Africa. In general, Indonesia and Laos are the least mechanized in terms of mungbean production in Southeast Asia while Thailand is the most mechanized.

Table 3 Most popular mungbean varieties in Southeast Asia and East Africa, in % of planted area in 2017–18 and showing the year of release

Cambodia			Indonesia			Laos		
Variety	**% area**	**Year**	**Variety**	**% area**	**Year**	**Variety**	**% area**	**Year**
DX 208[a]	40.9	–	Local varieties	39.6	–	Local varieties	63.4	–
Local varieties	15.9	–	Vima 1[a]	19.8	2008	Thuakyoyai (dark green)	31.6	–
V94-208[a]	15.6	1995	Vima 3[a]	10.8	2014	Thuakyoyai (light green)	5.0	–
CS-208	10.7	–	Kutilang[a]	5.9	2004			
Tra theiyn chay	6.6	–	Vima 2[a]	4.8	2014			
Tra sam daw	3.3	–	Betet[a]	3.4	1983			
Tra tan thaw	3.3	–	Perkutut[a]	2.0	2001			
CMB1[a]	2.7	2009	Murai	1.9	2001			
KK2	< 1	–	Sriti[a]	1.8	1992			
KK3	< 1	–	Sampeong	1.6	2003			
Cardy Chey[a]	< 1	2001	Walet[a]	1.4	1985			
Philippines			**Thailand**			**Vietnam**		
Variety	**% area**	**Year**	**Variety**	**% area**	**Year**	**Variety**	**% area**	**Year**
Other IVs	34.0	–	Chai Nat 72[a]	55.2	2000	DX 208[a]	44.5	–
Ramgo	10.8	–	Chai Nat 84–1[a]	22.6	2012	HL89-E3	15.5	1992
UPL Mg7	8.9	1989	KSP2[a]	18.1	1986	Local varieties	8.6	–
Local varieties	8.0	–	KSP 1[a]	2.3	1986	V94-208[a]	6.0	1999
NSIC 2002 Mg 13[a]	7.8	2002	Chai Nat 36[a]	1.0	1991	Other IVs	4.2	–
BPI Mg-9, Taiwan green[a]	7.6	–	Local varieties	< 1	–	VN 94-3	3.5	–
Australian, shiny	7.3	–	Uthong 1	< 1	–	V28	2.8	–
East West Super Yield	7.2	–				V91-15	2.5	1999
NSIC 2004 Mg 14[a]	2.0	2004				V87-13[a]	2.4	1999
NSIC 2007 Mg 15[a]	2.0	2007				NTB 01[a]	1.3	2004
NSIC 2002 Mg 12[a]	2.0	2002				HLDX7[a]	1.2	2012
Uganda			**Tanzania**			**Kenya**		
Variety	**% area**	**Year**	**Variety**	**% area**	**Year**	**Variety**	**% area**	**Year**
Local varieties	61.5	–	Local varieties	94.8	–	KAT N26	55.0	1998
NAROGRAM1[a]	18.4	2016	Nuru	2.1	1978	KS 20	32.2	1997
NAROGRAM2[a]	8.6	1982	Imara	3.1	1982	KAT N22	< 1	1998
Mauritias	5	1985				Ndengu Tosha[a]	< 1	2017
N26[a]	3.5	2017				Biashara	< 1	2017
Crystal	2	2016				Karembo[a]	< 1	2017
N22	1	2016				Local varieties	< 1	–

In % of area planted for the surveyed locations

"–" means not known. Only the top-10 improved varieties per country are shown

[a] Variety with WorldVeg-developed genetic material in its pedigree

In all countries, farmers sell most of their mungbean after harvest. Most of it is sold to middlemen who come to the farm to buy directly from farmers (Table 5). Mungbean production in these countries is therefore commercial rather than subsistence-oriented.

Bruchid beetles are the main insect pest in stored mungbean. Infestation can happen in the field and beetles can rapidly multiply in storage, particularly under humid conditions. Many farmers therefore sell their beans immediately after harvest. The use of control methods in stored mungbean is low for Cambodia and Laos (Table 5). Fumigation with phosphine tablets is applied in Thailand (10% of farmers) and Tanzania (7%). The use of fungicide or insecticide sprays is more

Table 4 Agricultural practices used by mungbean farmers in Southeast Asia and East Africa, in % of farmers unless indicated otherwise, 2017–18

Practice	Southeast Asia							East Africa			
	KHM	IDN	LAO	PHL	THA	VNM	Avg	UGA	KEN	TZA	Avg
Seed rate (kg/ha)	25	30	20	21	68	19	35	18	10	8	10
Certified seed	62	9	25	2	66	79	36	6	39	2	22
Seed recycling (cycles)	1	8	5	2	2	1	6	4	2	0	1
Seed treatment											
Insecticides	0	4	0	25	15	4	8	11	1	3	2
Fungicides	0	1	0	7	29	0	7	11	0	0	1
Bioagents	0	2	0	1	15	0	4	0	0	0	0
Biofertilizers	0	0	0	10	50	0	11	0	1	0	0
Line sowing	52	57	27	10	13	76	46	8	86	45	65
Seed broadcasting	48	43	73	90	87	24	54	92	14	55	35
Min. fertilizers, basal	12	14	0	7	26	63	24	1	17	0	9
Min. fertilizers, top	9	14	0	0	10	95	25	0	0	0	0
Min. fertilizers, foliar	58	56	11	85	83	58	65	1	43	3	25
Insecticides/fungicides	49	77	4	77	89	77	77	70	77	54	68
Herbicides to prepare land	36	43	18	2	8	74	37	1	4	22	11
Herbicides to defoliate	18	2	0	0	7	3	8	0	0	0	0
Mechanized											
Land preparation	99	31	43	70	94	87	63	88	90	55	76
Sowing	48	5	0	1	63	9	21	2	1	0	1
Weeding	1	2	7	0	67	14	17	0	50	0	27
Harvesting	36	2	4	0	95	0	24	1	0	0	0
Threshing	89	49	36	43	94	48	61	1	1	0	1

Cambodia (KHM), Indonesia (IDN), Lao PDR (LAO), Philippines (PHL), Thailand (THA), Vietnam (VNM), Uganda (UGA), Kenya (KEN), Tanzania (TZA). Avg. = Average all countries per region. Country averages for each practice are weighted by mungbean planted area in surveyed regions

Table 5 Postharvest practices used by mungbean farmers in Southeast Asia and East Africa, in % of farmers, 2017–18

Practice	Southeast Asia							East Africa			
	KHM	IDN	LAO	PHL	THA	VNM	Avg	UGA	KEN	TZA	Avg
% of harvest sold	95	89	93	85	88	91	89	73	81	83	81
Phosphine tablets	1	0	0	0	10	4	3	1	0	7	3
Insecticide/fungicides	2	0	0	34	42	4	13	10	41	5	25
Botanicals	1	0	4	34	5	17	5	29	0	7	5
Hermetic storage bags	8	27	0	20	0	72	27	3	28	26	25

Cambodia (KHM), Indonesia (IDN), Lao PDR (LAO), Philippines (PHL), Thailand (THA), Vietnam (VNM), Uganda (UGA), Kenya (KEN), Tanzania (TZA). Avg = Average all countries per region

common in Thailand (42%), Kenya (41%) and the Philippines (34%) while botanical methods are more common in the Philippines (34%) and Uganda (29%). The use of hermetic storage bags is high in Vietnam (72%) and are also used in Indonesia (27%), Kenya (28%), Tanzania (26%) and the Philippines (20%). Some experts indicated that farmers also use other methods; for instance, farmers in southern Laos (Kong District), were reported to store seed soaked in diesel in plastic bottles.

Production constraints and research priorities

Mungbean production constraints vary by production systems and agricultural practices. Table 6 lists twelve

Table 6 Mungbean production constraints in Southeast Asia and East Africa, ranked from 1 to 12 (1 being the most important), 2017–18

	Southeast Asia						East Africa		
	KHM	IDN	LAO	PHL	THA	VNM	UGA	KEN	TZA
Insect pests in production	6	1	4	8	1	2	1	2	3
Unstable markets	4	5	2	4	4	4	11	1	5
Lack suitable varieties	2	7	6	5	8	7	7	11	2
Lack of quality seed	1	4	7	1	10	11	5	10	1
Low price/market demand	3	8	1	2	2	9	8	3	4
Unstable weather	10	6	8	3	5	5	4	4	9
Plant diseases	5	2	11	12	3	1	2	5	8
Water shortages	9	11	10	6	6	9	10	12	12
Labor shortages	8	3	5	9	9	6	9	6	10
Insect pests in storage	11	9	3	7	11	3	3	8	6
Lack of extension support	7	10	9	10	12	10	12	7	7
Soil fertility	12	12	12	11	7	12	6	9	11

Cambodia (KHM), Indonesia (IDN), Lao PDR (LAO), Philippines (PHL), Thailand (THA), Vietnam (VNM), Uganda (UGA), Kenya (KEN), Tanzania (TZA)

constraints identified through the expert panels. The list is sorted in ascending order by the average ranks (unweighted by mungbean areas), thus showing the most important constraint first.

The main production constraints are therefore insect pests, which were ranked high in Indonesia, Thailand, Vietnam, Kenya and Uganda. Plant diseases were also ranked high in this group of countries. Other important constraints included unstable markets and low market prices, which was the main concern in Laos, but also important in Cambodia, Philippines, Thailand and Kenya. Experts indicated that there is often no clear information on market demand and mungbean prices set by traders do not always reflect supply and demand. Lack of suitable varieties and low-quality seed are two related constraints, which were ranked high in Tanzania and Cambodia. Unstable weather conditions, usually attributed to climate change by the experts, was reported to limit mungbean production in the Philippines, Thailand, Vietnam, Uganda and Kenya.

These results generally show that the production constraints are location-specific and cannot be generalized. National averages do not necessarily reflect the variation in constraints identified at sub-national levels. The full data set at subnational levels is available from the authors. Still, there was a common agreement among experts that research needs to develop locally-adapted mungbean varieties that are resistant to insect pests and plant diseases and tolerant to soil and weather conditions and suited to local market demands (e.g. sprouting, or food processing). Besides, there is a need to develop a strong network among value chain stakeholders to share information on production activities like cultivation techniques and markets.

Discussion

Implications for research and development

Mungbean production either grown in rotation in lowland cereal-based systems or intercropped with other crops in upland areas is an important food and cash crop for achieving sustainable growth while providing additional income to smallholder farmers in Southeast Asia and East Africa. Our study estimated that about 1.7 million farm households produce mungbean in the nine countries studied. We found that improved varieties occupied about 78% of the planted area in Southeast Asia and 61% in East Africa. However, the adoption of improved varieties was relatively low in Laos (35%), Uganda (30%) and Tanzania (25%), which may be interpreted as unexploited potential to improve yields through variety development and scaling.

The study found that the average age of improved varieties was 19 years in Asia, which shows a slow turnover of improved varieties. This is typical for open-pollinated crop varieties that rely on the public sector for research and seed production [22, 39]. A stronger involvement of the private sector in variety development and seed production would be beneficial, but may not happen naturally as mungbean seed production may not always be profitable for seed companies. This shows the need for public investment in mungbean research and development.

About 61% of the mungbean area in Southeast Asia was planted to varieties developed in the international mungbean breeding program of the World Vegetable Center, but in East Africa this was only 2%, which confirms that the impact of this program is mostly limited to Asia. It is, therefore, important for World Vegetable Center to support national mungbean programs in Africa to improve the existing mungbean lines as has been extensively done in Asia [12]. The use of international material was non-existent in Laos (0%) and relatively low in the Philippines (22%). The implication is that the international mungbean research needs to try and connect better to the national mungbean programs and also focus on Africa since there are about 0.7 million mungbean farmers in Africa and their yields are very low. An initiative in this direction is the establishment of the International Mungbean Improvement Network in 2016 to connect research organizations involved in mungbean research globally [11].

Variety development is not the only strategy to improving mungbean productivity. The study found limited adoption of cultivation practices such as seed treatment with bioagents (e.g. Trichoderma) or biofertilizers (e.g. rhizobium), which are known to have beneficial effects on mungbean yields under certain conditions. Fertilizer use was also limited in several countries. Local research and extension are needed to develop local recommendations for best practices regarding input use. Another important area of improvement is mechanization, increased levels of which will be required to maintain profitability as rising labor costs depress mungbean production. Thailand and Kenya have relatively high levels of mechanization, but mechanization in most other countries is limited to land preparation and sometimes threshing.

Implications for food security

Food security is defined as "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" [40, 41]. Food security no longer only means the absence of hunger but more generally implies access to healthy diets that protect against malnutrition in all its forms as well as non-communicable diseases [42]. More than 3 billion people globally could not afford a healthy diet in 2017 [42]. Increasing the productivity of nutritious food crops is an effective way of raising food supplies, lowering food prices and increasing the incomes of smallholder farmers.

Grain legumes are one category of nutritious food that are widely underconsumed [2]. Grain legumes constitute a small and declining fraction of overall dietary intake [43, 44]. The low crop yield of grain legumes is a major factor for their low availability and high prices in low- and middle-income countries [43]. The productivity growth of grain legumes has not kept pace with that of cereals [6]. Expanding legume production will also benefit the sustainability of cereal-based cropping systems by adding diversity and improving soil fertility. Therefore, increasing the role of mungbean and other grain legumes is an important aspect of better aligning food systems to sustainable land management and food security.

The adoption of improved varieties, as shown in this paper, is an important first step, but does not necessarily indicate improvements in yields or food security [8]. High adoption of improved varieties can be compatible with low yields in the presence of other constraints or low use of other inputs. For instance, Abate et al. [22] observed that Zimbabwe has released 23 maize hybrids and their combined adoption is 97%; yet the national maize yield was still less than 1 t/ha in 2013. Further impact studies are therefore necessary to understand the benefits of adoption. One study analyzed the economic impact of mungbean adoption in Myanmar and showed that four improved mungbean varieties generated aggregate economic gains of USD 1.4 billion from 1980 to 2016 [45]. This shows the potential of improved mungbean varieties to create impact [22].

Reflection on the method

The main disadvantage of the expert elicitation method is that estimates have an unknown confidence interval and may be subject to bias. Yigezu et al. [29] compared expert elicitation to farm surveys and DNA fingerprinting for lentil varieties in Bangladesh and found that expert panels overestimated the adoption of newer varieties relative to that of older varieties. Such cognitive bias is common to expert elicitation studies [33]. This is likely because crop experts will more easily identify newer varieties than older ones. Another source of bias is if seed used by farmers is not pure, but mixtures of different varieties. This may happen if farmers buy seed from the grain market rather than buy seed from formal seed suppliers. However, DNA fingerprinting will have similar challenges in this situation as the method relies on plant samples. Finally, we note that the composition of expert panels may influence the results. Unfortunately, our study did not record the composition of the panels (e.g. farmers, researchers, extension, etc.) in a systematic way, which prevented us from showing these data. While different expert panels may lead to different results, we note that the effect of individual experts is mediated by the fact that panels discuss the individual estimates and then form a consensus.

The advantage of the expert elicitation method is the relatively low cost of covering large geographical areas as shown by this study covering 0.8 million ha spread over nine countries. It would have been unrealistic to do this using DNA fingerprinting, although this may become easier in the future as costs decrease and new methods become available [46, 47]. Another advantage is the participatory nature of the method as estimates are made by local experts themselves while the researchers facilitate the process. This creates ownership of the data and increases the likelihood that stakeholders will find the data useful and will act on them.

Conclusions

Improved mungbean varieties have been widely adopted in the Philippines, Thailand, Kenya, Cambodia, Vietnam and Indonesia, but traditional varieties still dominate production in Laos, Uganda and Tanzania. The average age of improved varieties is 19 years in Asia and 12 years in East Africa. Efforts are therefore needed to develop, promote and scale out new and better varieties and improve access quality seed of suitable varieties. These varieties will need to be combined with locally adapted good agricultural practices as the study identified low adoption rates for most of these methods. While improved mungbean varieties from international mungbean improvement research are widely adopted by farmers in Southeast Asia, this is not case in Africa. Therefore, there is a need to better connect and coordinate international mungbean research in countries in Asia and Africa.

Abbreviations

FAO: Food and Agriculture Organization of the United Nations; ha: Hectares; IDN: Indonesia; KEN: Kenya; KHM: Cambodia; LAO: Laos; NARS: National Agricultural Research Systems; PHL: Philippines; t: Tons; THA: Thailand; TZA: Tanzania; UGA: Uganda; VNM: Vietnam; WorldVeg: World Vegetable Center.

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Authors' contributions

TS: methodology; data curation; formal analysis; writing—original draft; project administration. JO: methodology; data curation; formal analysis; writing—original draft; project administration. PeS: conceptualization; methodology; supervision; project administration; writing—original draft; funding acquisition. PB: formal analysis; investigation; writing—review and editing. ZMH: formal analysis; investigation; writing—review and editing. RTH: investigation; writing—review and editing. MOJ: formal analysis; investigation; writing—review and editing. JRK: formal analysis; investigation; writing—review and editing. RK: Formal analysis; investigation; writing—review and editing. NK: Formal analysis; investigation; writing—review & editing. EKM: Formal analysis; investigation; writing—review and editing. HM: Formal analysis; investigation; writing—review and editing. RMN: Investigation; writing—review and editing. LN: formal analysis; investigation; writing—review and editing. TTL: Formal analysis; investigation; writing—review and editing. SP: formal analysis; investigation; writing—review & editing. TP: formal analysis; investigation; writing—review and editing. ES: formal analysis; investigation; writing—review and editing. PoS: formal analysis; investigation; writing—review and editing. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article and its additional information files.

Ethics approval and consent to participate

Data for this study were collected through meetings of experts. Participation in these meetings was voluntary and virtually risk-free and data were anonymized.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Appendix

See Tables 7, 8.

Table 7 Adoption of improved varieties in Southeast Asia by country and subnational levels, 2017–18

Country/subnational location	Expert informants (persons)	Surveyed area planted (ha)	Improved varieties (% area)	WorldVeg-related varieties	
				% area adopted	Farmers reached (1000 s)[a]
Cambodia (total 2 zones)	16	30,794	79	60	16
Central Zone	9	10,520	67	55	5
Upper Zone	7	20,274	85	62	11
Indonesia (total 4 regions)	43	174,807	60	56	274
West Nusa Tenggara	15	21,080	90	72	36
South Sulawesi	13	28,618	80	78	53
Central Java	15	74,306	42	50	71
East Java	13	50,803	64	59	72
Lao PDR (total 3 regions)	25	1855	35	0	0
South	9	919	70	0	0
North	9	500	0	0	0
Central	7	436	0	0	0
Philippines (total 4 regions)	36	34,286	92	22	9
Ilocos	7	9972	99	10	1
Central Luzon	8	4647	100	17	1
Cagayan	12	13,826	100	36	6
Western Visayas	9	5841	55	15	1
Thailand (total 2 regions)	22	70,642	91	99	11
Upper Center	12	12,321	95	96	2
Lower Northern	10	58,321	90	100	9
Vietnam (total 2 regions)	28	66,569	84	58	176
Central Highlands	15	35,170	80	47	74
South Central Coast	13	31,399	88	71	102

Planted area based on national statistics for 2017–2018 (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 8 Adoption of improved varieties by country and subnational unit, 2017–18 in East Africa

Country/subnational location	Expert informants (persons)	Surveyed area planted (ha)	Improved varieties (% area)	WorldVeg-related varieties	
				% area adopted	Farmers reached (1000 s)[a]
Uganda (total 5 regions)	59	34,670	28	16	8
Teso Region 1	12	13,988	20	12	1
Teso Region 2	10	13,988	30	15	1
Acholi	12	5334	40	25	2
Lango	16	905	30	20	2
West Nile	9	455	30	20	2
Kenya (total 5 regions)	69	229,048	91	0.8	1
Makueni	12	89,444	90	1	1
Kitui	12	89,487	95	1	0
Machakos	12	12,097	80	0	0
Tharaka Nithi	14	30,584	90	0	0
Embu	19	7436	90	0	0
Tanzania (total 5 regions)	76	155,121	5	0	0
Mtwara	15	40,885	5	0	0
Tabora	16	26,582	4	0	0
Simiyu	15	46,819	5	0	0
Mwanza	15	36,294	5	0	0
Kilimanjaro	15	4541	10	0	0

See notes under Table 7

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References

1. Global Panel. Food systems and diets: facing the challenges of the 21st century. London: Global Panel on Agriculture and Food Systems for Nutrition; 2016.
2. Willett W, Rockstrom J, et al. Food in the Anthropocene: the EAT-Lancet commission on healthy diets from sustainable food systems. Lancet. 2019;393(10170):447–92.
3. Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, et al. Food security: the challenge of feeding 9 billion people. Science. 2010;327(5967):812.
4. Springmann M, Godfray HCJ, Rayner M, Scarborough P. Analysis and valuation of the health and climate change cobenefits of dietary change. Proc Natl Acad Sci. 2016;113(15):4146–51.
5. Ali M, Gupta S. Carrying capacity of Indian agriculture: pulse crops. Curr Sci. 2012;102(6):874–81.
6. Byerlee D, White R. Agricultural systems intensification and diversification through food legumes: technological and policy options. In: Knight R, editor. Linking research and marketing opportunities for pulses in the 21st century: proceedings of the third international food legumes research conference. Dordrecht: Springer; 2000. p. 31–46.
7. Gowda CLL, Rao PP, Bhagavatula S, editors. Global trends in production and trade of major grain legumes. In: International Conference on Grain Legumes: Quality Improvement, Value Addition and Trade, February 14–16, 2009; 2009; Indian Society of Pulses Research and Development, Indian Institute of Pulses Research, Kanpur, India.
8. Jha SK, McDermott J, Bacon G, Lannon C, Joshi PK, Dubé L. Convergent innovation for affordable nutrition, health, and health care: the global pulse roadmap. Ann N Y Acad Sci. 2014;1331:142–56.
9. Dwivedi SL, Lammerts van Bueren ET, Ceccarelli S, Grando S, Upadhyaya HD, Ortiz R. Diversifying food systems in the pursuit of sustainable food production and healthy diets. Trends Plant Sci. 2017;22:842–56.
10. FAO. Future smart food: rediscovering hidden treasures of neglected and underutilized species for Zero Hunger in Asia, executive summary. Bangkok: Food and Agriculture Organization of the United Nations; 2018.
11. Nair R, Schreinemachers P. Global status and economic importance of mungbean. In: Nair RM, Schafleitner R, Lee S-H, editors. The mungbean genome. Cham: Springer International Publishing; 2020. p. 1–8.
12. Schreinemachers P, Sequeros T, Rani S, Rashid MA, Gowdru NV, Rahman MS, et al. Counting the beans: quantifying the adoption of improved mungbean varieties in South Asia and Myanmar. Food Secur. 2019;11(3):623–34.
13. Agriculture Mo. Statistik Pertanian 2010, 2014, 2018. Jakarta, Indonesia: Statistic Indonesia; 2010, 2014, 2018.
14. MoAa C. Agricultural statistics. Bangkok: Office of Agricultural Economics; 2018.
15. Ministry of Agriculture FaF. Annual report and its future direction for 2019–2020. Phnom Penh: Ministry of Agriculture, Forestry and Fisheries; 2018.
16. Ministry of Planning and Investment. Statistical yearbook 2017. Vientiane Capital: Lao Statistics Bureau; 2018.
17. Ministry of Agriculture LaF. Economic review of agriculture. Nairobi: Central Planning and Project Monitoring Unit; 2015.
18. Philippine Statistics Authority. Crops statistics of the Philippines 2013–2017, regional-provincial. Quezon City: Philippine Statistics Authority; 2018.
19. Ministry of Agriculture in Tanzania. Data on mungbean area, production and yield (unpublished). Dodoma: Statistics Unit; 2018.
20. Kilimo Trust. Characteristics of green gram markets in the EAC. Kampala: Regional East African Community Trade in Staples (REACTS) project; 2017.

21. Ministry of Agriculture. 2016/17 Annual agriculture sample survey (AASS). Crop and livestock report. Dodoma: Ministry of Agriculture; 2018.
22. Abate T, Fisher M, Abdoulaye T, Kassie GT, Lunduka R, Marenya P, et al. Characteristics of maize cultivars in Africa: how modern are they and how many do smallholder farmers grow? Agric Food Secur. 2017;6(1):30.
23. Timu AG, Mulwa R, Okello J, Kamau M. The role of varietal attributes on adoption of improved seed varieties: the case of sorghum in Kenya. Agric Food Secur. 2014;3(1):9.
24. Nata JT, Mjelde JW, Boadu FO. Household adoption of soil-improving practices and food insecurity in Ghana. Agric Food Secur. 2014;3(1):17.
25. Morell M, Peakall R, Appels R, Preston L, Lloyd H. DNA profiling techniques for plant variety identification. Aust J Exp Agric. 1995;35(6):807–19.
26. Rabbi IY, Kulakow PA, Manu-Aduening JA, Dankyi AA, Asibuo JY, Parkes EY, et al. Tracking crop varieties using genotyping-by-sequencing markers: a case study using cassava (Manihot esculenta Crantz). BMC Genet. 2015;16(1):115.
27. Maredia MK, Reyes BA, Manu-Aduening J, Dankyi A, Hamazakaza P, Muimui K, et al. Testing alternative methods of varietal identification using DNA fingerprinting: results of pilot studies in Ghana and Zambia. In: MSU international development working paper No 149, October 2016, Michigan State University. 2016.
28. Kosmowski F, Aragaw A, Kilian A, Ambel A, Ilukor J, Yigezu B, et al. Varietal identification in household surveys: results from three household-based methods against the benchmark of DNA fingerprinting in southern Ethiopia. Exp Agric. 2018;55:371–85.
29. Yigezu YA, Alwang J, Rahman MW, Mollah MBR, El-Shater T, Aw-Hassan A, et al. Is DNA fingerprinting the gold standard for estimation of adoption and impacts of improved lentil varieties? Food Policy. 2019;83:48–59.
30. Dalkey N, Helmer O. An Experimental application of the DELPHI method to the use of experts. Manage Sci. 1963;9(3):458–67.
31. Krigsholm P, Zavialova S, Riekkinen K, Ståhle P, Viitanen K. Understanding the future of the Finnish cadastral system—a Delphi study. Land Use Policy. 2017;68:133–40.
32. Toumbourou T. Using a Delphi approach to identify the most efficacious interventions to improve Indonesia's forest and land governance. Land Use Policy. 2018. https://doi.org/10.1016/j.landusepol.2017.05.017.
33. Morgan MG. Use (and abuse) of expert elicitation in support of decision making for public policy. Proc Natl Acad Sci USA. 2014;111(20):7176–84.
34. Walker TS, Alwang J. Crop improvement, adoption and impact of improved varieties in food crops in sub-Saharan Africa. Wallingford: CABI Publishing; 2015.
35. Rashid MA, Hossain TMB. Adoption of wheat varieties in Bangladesh: expert elicitation approach. Bangladesh J Agril Res. 2016;41(3):491–505.
36. Tsusaka TW, Velasco ML, Yamano T, Pandey S. Expert elicitation for assessing agricultural technology adoption: the case of improved rice varieties in South Asian countries. Asian J Agric Dev. 2015;12(1):19–33.
37. Ochieng J, Schreinemachers P, Ogada M, Dinssa FF, Barnos W, Mndiga H. Adoption of improved amaranth varieties and good agricultural practices in East Africa. Land Use Policy. 2019;83:187–94.
38. Maredia M, Reyes B. Guidelines for collecting varietal release and adoption data. Objective 2.1. Organize the collection of crop germplasm improvement research related direct outcomes. Strenghtening impact assessment in CGIAR (SIAC) project. 2014. http://impact.cgiar.org/sites/default/files//docs/Guidelines-SIAC21-Activity_v7-4-25-14.pdf2014. Accessed 25 Jan 2019.
39. Erenstein O, Kassie G. Seeding eastern Africa's maize revolution in the post-structural adjustment era: a review and comparative analysis of the formal maize seed sector. Int Food Agribus Manag Rev. 2018;21(1):266448.
40. Committee on World Food Security. Global strategic framework for food security & nutrition (GSF). Rome: Food and Agriculture Organization of the United Nations; 2017.
41. Santeramo FG. Food security composite indices: implications for policy and practice. Dev Pract. 2015;25(4):594–600.
42. FAO, Ifad, UNICEF, WFP, WHO. The state of food security and nutrition in the world 2020. Transforming food systems for affordable healthy diets. Rome: FAO, IFAD, UNICEF, WFP and WHO; 2020.
43. McDermott J, Wyatt AJ. The role of pulses in sustainable and healthy food systems. Ann N Y Acad Sci. 2017;1392(1):30–42.
44. Pingali P. Agricultural policy and nutrition outcomes – getting beyond the preoccupation with staple grains. Food Secur. 2015;7(3):583–91.
45. Sequeros T, Schreinemachers P, Depenbusch L, Shwe T, Nair RM. Impact and returns on investment of mungbean research and development in Myanmar. Agric Food Secur. 2020;9(1):5.
46. Jaleta M, Tesfaye K, Kilian A, Yirga C, Habte E, Beyene H, et al. Misidentification by farmers of the crop varieties they grow: Lessons from DNA fingerprinting of wheat in Ethiopia. PLoS ONE. 2020;15(7):e0235484.
47. Setimela PS, Warburton ML, Erasmus T. DNA fingerprinting of open-pollinated maize seed lots to establish genetic purity using simple sequence repeat markers. South Afr J Plant Soil. 2016;33(2):141–8.

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