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Final report

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Contents

1 Acknowledgments

The project team thanks Mr. Xavier Martin, an experienced mungbean farmer from Australia for assessing the status of harvesters in Bangladesh, Myanmar and Pakistan and for his recommendations for mungbean harvesting.

2 Executive summary

Crop Desiccation: Mechanical harvesting of mungbean requires that green leaves and stems be desiccated before harvest. The assessment of the suitability of desiccants to aid mungbean harvesting revealed that Thiourea (10%) is effective and offers alternatives to glyphosate, with concerns about its use increasing in some countries.

Suitable Harvesters: Cereal harvesters currently available in the project countries are too aggressive for harvesting mungbeans and needed modifications. In Pakistan, significant progress has been made in modifying New Holland TC 5040 Harvester in reducing seed losses and NARC is actively promoting mechanical harvesting through farmer organisations. In Myanmar, harvest hubs have been formed and are actively using Kubota DC 70 G fitted with bean kits for hiring by farmers. BARI has teamed up with ACI Motors Ltd and will promote the use of Yanmar YH – 700 for mungbean harvesting.

Mungbean Varieties: The identification of a mungbean accessions with natural leaf senescence ability at pod maturity offers hope in the development of future varieties which would not require the use of chemical desiccants. These varieties will be extremely valuable to the high premium sprout market segment.

Gendered Impact on Laborers: Farm mechanization can promote the economic sustainability of small farms and, in the context of cereal-legume systems, strengthen plant protein-based diets, which support human health and environmental sustainability. However, mechanization inevitably displaces hired laborers who depend on manual farm work for their income. To analyse differential effects on women and men hired labor, we used primarily qualitative data from Myanmar and Bangladesh to test the hypothesis that the effects of mechanizing mungbean harvesting—which is now commencing in both countries—are likely to weaken hired women workers' economic and personal empowerment. The study focussed on rural landless women laborers as an important part of the agricultural labor force. The results broadly confirm the hypothesis, although there is variation between the research sites. Harvesting mungbeans is the only fieldwork task available to many landless women, particularly married women with children, in both countries. Gendered restrictions on women's mobility and their role as family caregivers, as well as norms about appropriate work for women and men, restrict women's options regarding alternative work both locally and further away. The effects are likely to be particularly negative in locations with minimal off-farm economic diversity and more restrictive gender norms. Overall, men across all sites will be less affected since their participation rates in harvesting and post-harvest processing are low. They are less restricted by gender norms and can travel freely to find work elsewhere. However, women and men in low asset households will find it problematic to find alternative income sources. Less restrictive gender norms would help to mitigate the adverse effects of farm mechanization. It is important to invest in gender-transformative approaches to stimulate change in norms and associated behaviors to make a wider range of choices possible.

Socio-Economic Analysis: The study analysed, ex-ante, the likely social and economic trade-offs of mechanizing the mungbean harvest in Bangladesh and Myanmar. We used a mixed methods approach combining survey data from 852 farm households with in-depth interviews in four villages. Partial budget analysis shows that mechanical harvesting of mungbean is not yet profitable for most farms. There is nevertheless an incentive to mechanize as the timeliness of the harvest reduces the risk of losses from weather shocks. Men and women farmers expect time savings and reduced drudgery. The results confirm that hired workers – most of them landless married women with limited access to other sources of income - depend on manual harvesting for income and status in both countries. In the short term, farmers are likely to combine manual harvests and a final mechanized harvest of the indeterminate crop. This could mediate the impact on hired workers. However, in the long term, it will be necessary to facilitate income-generating opportunities for women in landless rural families to maintain their well-being and income.

3 Background

3.1 Partner country and Australian research and development issues and priorities

In **Bangladesh**, mungbean ranks third in area of cultivated pulses. Bangladesh imports two thirds of pulses consumed in the country, consequently the market requires significant additional domestic production at a competitive price. Pulse wholesale prices are high (>100 Taka per kg, corresponds to AUD 1.69), thus cultivation and trade of these crops generate significant income. Mungbean is mostly grown as a rotation crop in the cereal-based cropping system. In the south, farmers follow a rice-lentil/mustard-mungbean system, while in the north, a rice-wheat-mungbean system is common. The current production area comprises 182,000 ha and yields 198,000 t/year (Krishi Diary, 2015). Increased production of short-duration mungbean in the *kharif* (rainy or summer) season will play an important role in diversifying this cropping system, as traditional *rabi* (winter season) pulses such as chickpea and lentil are increasingly displaced by wheat. Bangladesh's three main mungbean production zones with distinct growing seasons are in the north (sown March/April), the central-west (sown early March) and the south (sown January). The most popular variety, BARI mung 6, originating from the WorldVeg program, has been grown since 2003 and yields about 1.5 t/ha. About 80% of the mungbean production comes from Rajshahi, Jessore and Barishal regions.

Mungbean is an important rotation crop for rice farmers in **Myanmar**. Mungbean has an average benefit-cost ratio of 3.4, as compared to 1.4 for rice. As rice production is less profitable for smallholders, farmers increasingly depend on mungbean as a rotation crop for cash income (Win *et al* , 2009). In contrast to India and Bangladesh, Myanmar is a net exporter of mungbean. The crop is mostly grown during and after the monsoon season on about 1.12 million ha, with a mean yield of about 1.29 t/ha (ranging from 0.44 t/ha in Taninyharyi to 1.67 t/ha in East Bago). Mandalay, Sagaing and Magwe regions account for over 80% of the production area.

Mungbean is one of the most important *kharif* pulses in **Pakistan** but it is also grown during the spring season. Mungbean is grown on an area of 127,500 ha with total production of 98,900 t (Agriculture Statistics of Pakistan, 2015-16). Eighty percent is produced in the country's Thal region which consists of five districts of Bhakkar, Layyah, Mianwali, Khushab and Jhang. The region is known as the traditional area of mungbean production (Nasir *et al.,* 2016).

Expanding the production and productivity of mungbean in Bangladesh, Myanmar and Pakistan would lead to increased availability of a good source of vegetable protein for local communities and for export. It would also potentially increase soil fertility through nitrogen fixation. In Bangladesh, mungbean makes an important contribution to national food and nutrition security as most of the production is consumed, whereas in Myanmar mungbean is an economically important export crop with a production 1.6 million t/year and average yield of 1,320 kg/ha. However, the expansion of the crop and the profits from the crop are limited because the costs of harvesting is high due to labour shortage at the time of harvest (Islam *et al.*, 2013). Traditionally, crops were left standing and hand-harvested several times as the pods progressively matured. As this has become more expensive, hand harvesting now comprises of cutting the plant, leaving it in the field for a week or two for sun-drying and subsequent mechanical threshing. This delays the sowing of the subsequent rice crop, exposes the grains to rain damage and results in lower crop yields. Harvesting mungbean too early results in the loss of immature pods, while harvesting too late results in losses from pod shattering. Harvesting and threshing by hand are time-consuming and involve drudgery, particularly for women. Mechanisation suitable for local cropping systems in the partner countries can provide a cost-effective alternative to manual harvesting; it is likely to speed up harvesting and increase profits from mungbean production, which could promote the further expansion of the mungbean area.

The project is aligned with partner country priorities as determined from information gathered when starting the International Mungbean Improvement Network (IMIN: CIM-2014-079).

In Bangladesh, poverty reduction, improved human nutrition and improved livelihoods are the main outcomes targeted by the project. The Agriculture Sector Development Strategy, a background paper for Bangladesh's 7th Five Year Plan (2015-16 to 2019-20), suggests the need for

> "*rapid expansion of mechanization to compensate for the shortage of draft power, farm labour and the declining interest of young people to stay in agriculture. Farm mechanization can help in improving productivity, reducing the cost of production, increasing input use efficiency (water, seed, fertilizer, land and labour) and achieving timeliness of crop production operations. Agricultural mechanization is also required to reduce the turn-over time. There is a need for development of more efficient and less costly equipment so that farmers can benefit. In the context of market economy, emphasis will have to be given to the collaborative role of public and private sectors in technology development and diffusion."*

and it also states that:

> *"Use of machinery reduces harvest and post-harvest losses, production costs, and drudgery of farm workers; ensures timely operation, higher precision and quality produce. The Government will play its pro-active role in popularizing the use of selected demand-led agricultural tools and machineries through field demonstration and imparting training to operators and mechanics for improving their technical know-how and skills in machinery operation, repair and maintenance."*

In Myanmar, increased competitiveness and profitability of mungbean and the development of the private sector agricultural input suppliers are priorities. The National Strategy on Poverty Alleviation and Rural Development (NSPARD) states that:

> *"[…] postharvest works of pulses are still weak in using machines. Harvesting, threshing, grading and cleaning process are still made by hand […]".*

Myanmar's Country Statement on Agriculture prepared by the Ministry of Agriculture and Irrigation (MAOI) in 2014 indicates that the ministry supports the transformation of conventional agricultural practices to advanced technology practices and mechanized farming. Amongst the reform areas in agriculture it is mentioned that:

> *"[…] converting conventional small-scale farms into mechanized farms in the form of acre- or hectare-plots in order to change manual farming into mechanized farming."*

Mechanical harvesting of mungbean is being implemented in Pakistan as part of the USAID-funded Agricultural Innovation Program (AIP). Here, and in previous research in India it was shown that small-scale wheat and rice harvesters can be modified to effectively handle mungbean, but it is generally necessary to apply a chemical desiccant to the crop prior to mechanized harvesting to avoid the build-up of gummy residues of plant sap in the harvesters. Although some information about pre-harvest crop treatment options is available from past work led by WorldVeg, little is known about the fate of the chemical desiccants and whether there are potential problems with residues in the soil or in the produce. The project would deliver on Pakistan's priority of improving legume production, productivity and profitability. Research on mechanical harvesting is more advanced in Pakistan but the inclusion of Pakistan in this project is the result of a request of the government of Pakistan, as relayed to the project team by the ACIAR country office in Islamabad.

This project is aligned with the ACIAR priority of improving competitiveness (through cost reduction) and sustainability (contribution to farming system diversification and intensification).

It is also aligned with the Australia Aid agriculture policy strategy Objective 1 “Increase contribution to national economic output”, Objective 2 “Increase income for poor people”, and Objective 3 “Enhance food, nutrition security” through Pillar 2 “Innovating for productivity and sustainable resource use”. It contributes to ACIAR performance indicators 1 (prosperity), 2 (private sector), 3 (poverty), 4 (women empowerment), 5 (Indo-Pacific), 7 (partners), and 8 (value for money).

4 Objectives

4.1 Project aim and objectives

Aim: Establish and validate a practical and economically viable system to mechanically harvest mungbean from smallholder fields in Bangladesh, Myanmar and Pakistan.

Objectives:

1. Develop a package of cropping practices to facilitate mechanical mungbean harvesting, including safe and effective use of crop desiccants. (This will be done in the three countries, building on significant work already done in Pakistan).
2. Develop the most effective and economic mungbean harvesting method suited to Bangladesh, Myanmar and Pakistan.
3. Communicate the likely impact of a change in harvesting practices on women to all stakeholders and provide harvest management options that would potentially benefit the livelihoods of women (in all three countries).

5 Methodology

5.1 Develop a package of cropping practices to facilitate mechanical mungbean harvesting, including safe and effective use of crop desiccants.

Mechanical harvesting requires that green leaves and stems be desiccated before harvest. Various chemical desiccants are usually available but not all are equally effective or safe to farm workers and consumers. Therefore, in the project, we assessed what combinations of available chemical desiccants and application methods are the safest and most effective for mungbean under the backdrop of non-usage of harsh herbicides/desiccants (Paraquat and Diquat).

A total of 21 trials were conducted in four countries i.e. Bangladesh (7 trials), India (2 trials), Myanmar (8 trials) and Pakistan (4 trials) across different locations to understand the effect of different chemicals on plant desiccation. Different desiccation chemicals were tested on popular varieties such as BARI Mung 6 and BARI Mung 7 in Bangladesh, Yezin 11 in Myanmar, NM 11 in Pakistan and NM 94 in India (Table 1).

Table 1 List of trials conducted for chemical desiccation across project partner countries from 2018 to 2021.

Country	Location	Season	Year	Treatments	Variety
Chemical Desiccation Trials					
Bangladesh	Ishwardi	*Kharif1*	2018	10	BARI Mung 6
Bangladesh	Ishwardi	*Kharif1*	2019	9	BARI Mung 7
Bangladesh	Gazipur	*Kharif1*	2019	9	BARI Mung 6
Bangladesh	Rangpur	*Kharif1*	2019	9	BARI Mung 6
Bangladesh	Gazipur	*Kharif1*	2021	5	BARI Mung 7
Bangladesh	Rangpur	*Kharif1*	2021	5	BARI Mung 7
Bangladesh	Madaripur	*Kharif1*	2021	5	BARI Mung 7
Myanmar	Tatkone	Monsoon	2018	8	Yezin 11
Myanmar	Sebin	Monsoon	2019	7	Yezin 11
Myanmar	Yezin	Monsoon	2019	7	Yezin 11
Myanmar	Tatkone	Monsoon	2020	5	Yezin 11
Myanmar	Sebin	Monsoon	2020	5	Yezin 11
Myanmar	Yezin	Monsoon	2020	5	Yezin 11
Myanmar	Sebin	Monsoon	2021	5	Yezin 11
Myanmar	Yezin	Monsoon	2021	5	Yezin 11
Pakistan	Bhakkar	*Kharif*	2018	10	NM 11
Pakistan	Islamabad	*Kharif*	2018	10	NM 11
Pakistan	Islamabad	*Kharif*	2019	9	NM 11
Pakistan	Islamabad	*Kharif*	2020	5	NM 11
India	Hyderabad	*Kharif*	2017	11	NM 94
India	Hyderabad	*Kharif*	2018	10	NM 94

Methodology of desiccation experiments

The trials were conducted at multiple sites across years in each project partner country from 2018 to 2021 using popular varieties. The chemical treatments selected for different countries were applied at 85% pod maturity stage keeping one treatment as control (without chemical desiccant spray) for comparison. The stage of desiccation application was decided based on seed moisture content in matured pods. For estimation of moisture content, selected visibly dried pods at random in a block (at 80-85% maturity) and seeds were threshed for moisture content using a seed moisture meter. The crop stage with a seed moisture content of around 10-11% was selected for desiccant spray. The desiccants were sprayed only once in morning hours when the sun is bright and no irrigation to blocks on the day of spraying was given. The desiccant concentrations were prepared using water and spraying was done using all the personal protection equipment (PPE). The observations were started after 24 hours post spray. The traits such as desiccation scores, leaf defoliation, leaf dryness, whole plant dryness, leaf defoliation, and the number of days required for leaf, pod, and whole plant drying after desiccant application, seed discoloration, pod shattering, pod, and seed yield were recorded across trials. The chemical residue analysis of dried seed samples harvested from different desiccant treatments was analyzed for chemical residue analysis. The random seed samples from different desiccant treatments were tested for seed germination. The methodology followed for each trait is given below.

1. **Desiccation score:** The desiccation scores were recorded on a 1 to 5 scale where 1 represent – Green, 2- Green tending to grey, 3- Grey, 4- Brownish grey and 5- Brownish black/ Darkish Brown. The scoring was started 24 h after desiccant application.
2. **Leaf defoliation:** Leaf defoliation was recorded on 0 to 5 scale where 0= No defoliation occur, 1= 1-3 leaves/plant defoliated, 2= Few leaves (>3 leaves/plant defoliated), 3=Half of total leaves defoliated, 4= All leaves defoliated except few and 5= All leaves defoliated.
3. **Seed discoloration:** Seed discoloration scores were recorded on 1 to 5 scale where 1= No discolor, 2= A bit discolor, 3=Discolouration occurred more than little, 4= about 80 % discolored, 5= Entire seed are discolored. The scoring was done when seeds were properly dried.
4. **Leaf dryness score:** Leaf drying scores were recorded on 0 to 5 scale starting from next day of desiccation application: 0= Green, 1=Light or dull green, 2-Green tending to grey, 3- Grey, 4-Brownish grey, 5- Brownish black / Darkish brown
5. **Number of days for leaf drying after desiccant application (empirical assay):** The number of days required for complete leaf drying after desiccant application are recorded after 24 h of desiccant application till leaves in plots reach to either score ≥3.
6. **Number of days for pod drying after desiccant application:** The number of days required for complete pod drying after desiccant application are recorded
7. **Number of days for the whole drying after desiccant application:** The number of days required for complete whole plant drying after desiccant application are recorded
8. **Pod shattering:** Pod shattering if noticed was recorded based on 1 to 5 scale where 1 represents no shatter whereas 5 represents complete shattering.
9. **Pod and Seed yield (per plot basis):** Pod and seed yield was measured on plot basis using an electronic weighing balance after complete drying. The data were recorded in g/plot and converted to kg/ha for analysis.
10. **Seed loss (%) (fallen on ground)** – The % seed loss was recorded after final seed harvest on a per block basis. The seed fallen on a one square meter area were collected and measured using electronic weighing balance and calculated the total seed loss per plot. One square meter wooden/iron frame was used to collect the seeds fallen within

the frame as shown in Figure 1. The formula for calculating percent seed loss is given below.

% Seed loss = (Amount of seeds fallen on the ground per plot / (Total seed yield per plot +total seed fallen on the ground per plot) *100

Figure 1. Percent seed loss was calculated through collecting the fallen seeds on the ground in one square meter area

5.2 Develop the most effective and economic mungbean harvesting method suited to Bangladesh, Myanmar, and Pakistan

5.2.1 Mechanical Harvesting Experiments:

A total of eleven trials were conducted in three project partnering countries i.e. Bangladesh (1 trial), India (2 trials), Myanmar (7 trials) and Pakistan (3 trials) across different locations to evaluate the efficiency of mechanical harvesting in mungbean using with and without desiccants compared to the traditional harvesting practices in these countries (Table 2). The experiments were conducted with a set of treatments including modified harvester with and without desiccant chemicals and farmers' preferred harvesting practices and their combinations.

Table 2. List of trials conducted for mechanical harvesting across project partner countries from 2018 to 2021.

Country	Location	Season	Year	#Treatments	Variety	Harvester Model	Harvester modification tested
Bangladesh	Ishwardi	*Kharif1*	2019	5	BARI Mung 7	4L-BZ 110 KYM	The cereal harvester settings
Myanmar	Tatkone	Monsoon	2018	5	Yezin 11	Kubota DC 70G	Cutting Pickup Reel Diameter x Width (mm)-900 x 1903
Myanmar	Sebin	Monsoon	2018	5	Yezin 11	Kubota DC 70G	
Myanmar	Tatkone	Monsoon	2019	3	Yezin 11	Kubota DC 70G	

Myanmar	Sebin	Monsoon	2019	3	Yezin 11	Kubota DC 70G	Height Adjustment- Hydraulics Gathering Length (mm)- 2075 Cutter Bar Length (mm)-1980 Cutting Height Range (mm)-819 Threshing/Separating Threshing System (mm)- Spike Tooth Axial Flow Threshing Cylinder Diameterx Length (mm)- 620 x 1650 Revolutions (rpm)-560 Concave Area (m2)- 0.9 Sieve Case Length x Width (mm)- 1375 x 840
Myanmar	Tatkone	Monsoon	2020	4	Yezin 14	Kubota DC 70G	
Myanmar	Sebin	Monsoon	2020	4	Yezin 14	Kubota DC 70G	
Myanmar	Sebin	Monsoon	2021	3	Yezin 14	Kubota DC 70G	
Pakistan	Islamabad	*Kharif*	2019	5	NM 11	TC-5040	Drum Speed-650 RPM; Fan Speed – 1000 RPM
Pakistan	Islamabad	*Kharif*	2020	5	NM 11	TC-5040	Drum Speed-670 RPM; Fan Speed – 1000 RPM, Top Sieve Opening - 15 mm Bottom Sieve Opening- 10 mm
Pakistan	Islamabad	*Kharif*	2021	4	NM 16	TC-5040	

5.2.2 Methodology of harvesting experiments

The mechanical harvesting experiments were conducted using popular varieties of respective project partner countries. The experiment was conducted with plot size 100 sqm (33m Lx 3m W colored in red) keeping 25 m gap between replication and around 10 m between plots for machine movement (Figure 2). The treatments such as manual (traditional) harvesting, using Cereal harvester without desiccant, using cereal harvester with desiccant, using modified harvester without desiccant and using modified harvester with desiccant were initially tested across countries. The combination of manual and mechanical harvesting was also tested using different treatments such as 3 hand pickings following farmers' preference, 1 handpicking + mechanized harvest with desiccant, 2 hand pickings + mechanized harvest with desiccant, and only mechanized harvest with desiccant. The time of desiccant application for some of the treatments where the chemical desiccant is required was decided based on seed moisture content. For estimation of moisture content, selected visibly dried pods at random in a block (at 80-85% maturity) and seeds were threshed for moisture content using a seed moisture meter. The crop stage with a seed moisture content of around 10-11% was selected for desiccant spray. The desiccants were sprayed only once in morning hours when the sun is bright and no irrigation to blocks on the day of spraying was given. The desiccant concentrations were prepared using water and spraying was done using all the personal protection equipment (PPE). The methodology for traits recorded from these trials is given below.

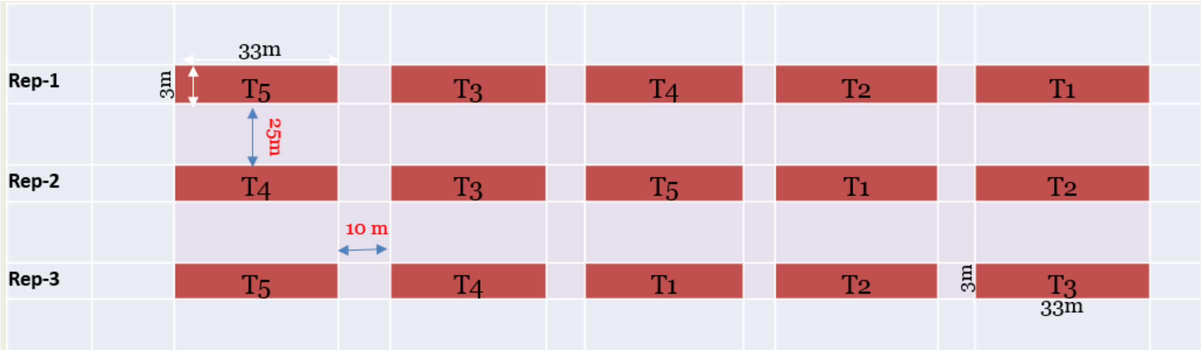

Figure 2. Experimental layout followed for mechanical harvesting trials across project partner countries.

1. No. of days for leaf drying after desiccant application (empirical assay): The number of days required for leaf drying was recorded for those treatments where desiccant application was done.
2. No. of days for pod drying after desiccant application: The number of days required for pod drying was recorded for those treatments where the desiccant application was done.
3. No. of days for whole plant drying after desiccant application: The number of days required for pod drying was recorded for those treatments where the desiccant application was done.
4. Pod and Seed yield (per plot basis): Pod and seed yield was measured on plot basis using an electronic weighing balance after complete drying. The data were recorded in g/plot and converted to kg/ha for analysis.
5. % of whole seed: The whole seed were separated from 100 g random samples and measured on an electronic weighing balance to calculate the % whole seeds.
6. % of broken seed: The broken seeds were separated from 100 g random samples and measured on an electronic weighing balance to calculate the % broken seeds.
7. % of discolored seed: The discolored seeds were separated from 100 g random samples and measured on an electronic weighing balance to calculate the % discolored seeds.
8. Seed loss (%) (fallen on ground) – The % seed loss was recorded after final seed harvest on per block basis. The seed fallen on a one square meter area were collected and measured using electronic weighing balance and calculated the total seed loss per plot. One square meter wooden/iron frame was used to collect the seeds fallen within the frame as shown in Figure 2. The formula for calculating percent seed loss is given below.

   % Seed loss = (Amount of seeds fallen on the ground per plot / (Total seed yield per plot +total seed fallen on the ground per plot)*100

5.2.3 Scoping visit in Bangladesh and Myanmar

The initial scoping visits (May 2018) were done in Bangladesh and Myanmar to know the status of mechanization at respective NARS and private service providers and also to understand the suitability of local machines for harvesting mungbeans (Figure 3, 4, 5 & 6). The assessment of available harvesters (Table 3 & 4) was done to know how to set up local machines to make them work better in harvesting mungbeans. The assessment identified that some of the essential additional parts, suppliers, and/or trainers are needed to implement the new harvesting system successfully.

Table 3. Assessment of harvesters (score out of 10) available in Bangladesh

Manufacturer/ Model	Reaper	Thresher	Winnower	Operation Mode	Reliability	Durability	Estimated Price (USD)
TARO TR120	1 (HF)	NA	NA	Walk behind	8	8	1,000-1,500
HF- 1 ACI	1 (HF)	5	3	Ride on	3	3	8,000-9,000
4L -80 Mingsin	6	5	4	Ride on	3	2	1,500-5,000
Yanmar YH150	7	6	6	Ride on	7	7	10,000-15,000

Figure 3. Scoping visit to Bangladesh A) Bangladesh Agriculture University and B) ACI motors Dhaka, Bangladesh.

Figure 4. Scoping visit to Myanmar – Agriculture Mechanization Department

Figure 5. Harvesters being used for harvesting of different cereal crops in Bangladesh

Figure 6. Harvesters being used for harvesting of different cereal crops in Myanmar

Table 4. Assessment of harvesters (score out of 10) available in Myanmar.

Manufacturer/Model	Reaper	Thresher	Winnower	Operation Mode	Reliability	Durability	Estimated Price (USD)
Daedong DSM72	1 (HF)	4	4	Ride on	6	5	15,000-30,000
FOTMA 4L Z - 4.0Z	5	6	5	Ride on	3	3	10,000-20,000
CLAAS Tiger 40	7	8	8	Ride on	8	8	40,000-57,000
Kubota DC 70 G	6	7	6	Ride on	7	7	30,000-50,000

5.2.4 Suitability of Harvester

For tough crops such as cereals especially rice, maize, and wheat can tolerate the aggressive harvesting process through combined harvesters. It requires higher velocity/impact elements, greater reliance on Archimedes screw/augers, vacuum winnowing rather than accelerated air therefore specialty rice harvesters compromise the harvesting in other crops, particularly pulses. However, legumes such as mungbean need gentle processes and modifications in the harvesters. The adjustability of the process is low on specialty (Asian) rice harvesters. Based on assessments, critical adjustments/modifications in features identified are listed below.

- Most harvesters will need process speed reduction
- Focus on reaper (cutter bar) features
- Adjustable low cutting height
- The efficiency of cutting/reaping
- Reel function and action
- Need for protection from stones/foreign objects
- Winnowing and grain transfer
- Bruising/scoring/splitting
- Use of augers/Archimedes screw
- Bucket/paddle elevators/augers
- Gravity is still free

Harvester Improvements: Based on the critical modification in features identified, some of the planned improvements in existing harvesters are listed below.

- Crop lifters/quick attach lifters
- Cutter bar end dividers
- Adapta-gap systems/double cut
- Vibramat, Air Reels, Draper belts
- Thresher/Concave/Beater speed adjustment
- Brush augers
- Fixed/Adjustable Chaffer/Sieve
- Dirt screens
- Grain bin load/unload systems

Dr Ram Nair, Mr. Xavier Martin and Mr. Kyaw Myo Aung visited to see different combined harvesters such as Kubota, Yanmar and CLAAS at Bago region (Dike U, AMD office). Of these, CLAAS was mostly used in Bago region, Kubota and Yanmar was mostly used in the Yangon region. The sites for conducting the trials of this project were Tatkone and Sebin Research farm where Kubota is available. The AMD department of DAR supported to go with Kubota Combined harvester in these project sites.

5.3 Communicate the likely impact of a change in harvesting practices on women to all stakeholders and provide harvest management options that would potentially benefit the livelihoods of women

5.3.1 How Will Mechanizing Mungbean Harvesting Affect Women Hired Laborers in Myanmar and Bangladesh?

Quantitative Research

The quantitative research used a stratified sampling strategy to interview mungbean farmers in major mungbean producing areas of Bangladesh and Myanmar. Data collection took place between July 2018 and February 2020. One set of survey questions related to farmer labor hiring practices. Gender-disaggregated labor data were collected separately for 11 activities from ploughing through to transporting the harvest to the market. This included data on labor provided by hired laborers, family laborers, laborers that did not receive monetary payments, and children. For each type of laborer, and activity, respondents reported the number of days of work, the average number of persons involved, and the average number of hours spent. From this we calculated standardized 8-h labor-days. Extreme outliers were removed. (Where the total labour input per hectare was more than two inter-quartile ranges above the 3rd quartile, we replaced it with the largest remaining value in the country. We replaced 9 outliers in Bangladesh and 26 in Myanmar. All contributing labour sources and their wages were reduced by the same factor (Farnworth et al. 2020).

In Myanmar, the Magway and Sagaing Regions were chosen to represent the Central Dry Zone while Bago and Yangon were chosen to represent Lower Myanmar. In Bangladesh, the Natore and Pabna Districts were selected to represent the north and Jhenaidah to represent the south. Patuakhali was also included, though quantitative data collection was prevented by the COVID-19 pandemic. In each administrative area the research team identified three townships (in Myanmar) or four unions (in Bangladesh) where mungbean production is concentrated. Two to three villages per township/district were randomly selected to ensure 125 interviews per region/district. The survey included 334 mungbean farmers from 40 villages in Bangladesh and 518 farmers from 44 villages in Myanmar. As the sampling is not proportional to the area planted with mungbean, we weight the data based on the official statistics of mungbean production area in the regions/districts and the area planted by each farmer. The weights represent the importance of the area planted with mungbean by each farm compared to the national mungbean production area (Farnworth et al. 2020).

Qualitative Research

The qualitative research sites were purposively selected from the quantitative research sampling frame based on the national partners' knowledge of the sites. Seven research activities were conducted in each research site. These included four sex-disaggregated focus group discussions (FGDs), (4 with women, 3 with men) held with facilitators of the same gender, and one wife-husband activity. Additional activities informing this study include a community profile (mixed gender); and a mungbean value chain analysis with associated individual key informant interviews (KIIs) (mixed gender). Tools were partly based on the GENNOVATE (gender, norms and innovation) research guide (Farnworth et al. 2020). FGDs 1 and 2 investigated the role of mungbean in the local agricultural system and its relative importance by activity—compared to other income generation opportunities—in women's and men's livelihoods. FGD 3 asked a couple to reflect individually and then together on their visions for the future. The discussion focused on (gendered) factors hampering or facilitating vision realization. FGD 4 asked respondents to explore the respective abilities of women and men to respond to mechanization through innovating into new livelihoods. FGD 5 asked women to reflect on their sense of empowerment. As part of these exercises, respondents were asked to reflect on who makes key decisions on the topics discussed, and in relation to the management of their asset portfolios. In all FGDs, forces driving system change, and their effects, were explored. To help understand gender norms, and if they are changing, all respondents in all FGDs were asked to discuss what gender equality meant to them.

Sampling criteria were as follows: 6 to 8 respondents per sex-disaggregated FGD. They had to be landless women and men workers known to regularly participate in mungbean harvesting (or in mungbean production and post-harvest tasks). Every respondent had to come from a different household, and respondents had to be drawn from different locations in each community. Respondents for the community profile (average 8 per community, women and men) were expected to be of high standing in the community and to be able to contribute diverse knowledge: for instance, elected village leaders, health care staff and teachers. The value chain exercise was conducted more opportunistically, with respondents selected on the basis of their known participation in the mungbean value chain.

Village 1 is in Lower Myanmar. It had 917 households in 2019. Of these, 600 HH (around two thirds) were landless and worked as hired laborers. We met members of 52 households (8.67% of eligible households). Village 2 in the Central Dry Zone in Myanmar had 214 households in 2019. Of these, 98% (210 households) provided hired workers. About one third (30% = 63 households) worked primarily as agricultural laborers. Of these, we met with 46 households (73% of eligible households). Village 3 in northern Bangladesh had around 785 households. Of these, 456 households provided hired labor (58%) and we met members of 30 such households (6.6%). Village 4 in southern Bangladesh had 687 households in 2019 with 376 providing hired labor (54%). Of these, we met representatives of 54 (14.3%) of the eligible households.

5.3.2 Ex-Ante Socioeconomic Impact Evaluation of Mechanized Harvesting of Mungbean in Bangladesh and Myanmar

Conceptual Approach

We used a mixed-methods approach to provide a more complete picture of factors driving mechanization, its potential impacts and tradeoffs. To understand the economic motivation of farmers and the extent of the possible employment effects, we describe the results of a quantitative study and conduct an ex-ante partial budget analysis. Qualitative data provide information on the importance of other motivations for mechanization. To understand the potential impacts of mechanization on drudgery and employment among family members and hired laborers, we built upon estimates of labor demand. We com- bined this with insights from qualitative data to describe how these changes are likely to affect livelihoods.

Quantitative Data

Quantitative data were collected through a household survey among mungbean producers in Myanmar and Bangladesh. Data were collected from July 2018 to February 2020 using a stratified random sample from the major mungbean producing areas in Myanmar and Bangladesh. In Myanmar, we selected Magway and Sagaing Regions to represent the Central Dry Zone and Bago and Yangon Regions to represent Lower Myanmar. In Bangladesh, Natore and Pabna Districts were selected to represent the north and Jhenaidah District to represent the south. In each of these locations, the research team, using secondary data, identified three townships (in Myanmar) and four unions (in Bangladesh) where mungbean production is common. From each township/district, we then randomly selected 2–3 villages, which provided 125 sample observations per region/district. The total sample included 334 mungbean farmers from 40 villages in Bangladesh and 518 farmers from 44 villages in Myanmar. In Myanmar, 24 farmers had already adopted combine harvesting in mungbean production and were therefore excluded in part of the analysis. As the sample size was not proportional to the total mungbean area per location, survey weights were used to estimate means at the national level (Depenbusch et al. 2021).

The person in the household mostly involved in mungbean production was selected as primary respondent. The survey collected data on production methods, crop yield, revenue and cost of each mungbean production cycle. It also collected detailed data on farm labor use in mungbean such as the number of days and hours spent on an activity by household members and hired workers, disaggregated by age category and gender. These data were converted to standard 8-h labor days in the analysis. We also collected data on the gross revenues and costs of all other crop, livestock and enterprises of the household. These data were used to estimate the household income. To measure perceptions about mechanized harvesting respondents were asked for their support of statements on the mungbean and rice harvests, using a five-point Likert scale. If the primary respondent was a man, the questions were also asked to the woman in the household who was most involved in the mungbean production. Finally, the survey captured basic household data such as family composition, age, education, asset ownership and income sources. We added questions on the rice harvest to understand the cost structure in its mechanized harvest. Where a combine was used, we also asked for an estimate of the hypothetical manual harvesting cost.

Qualitative Data

The qualitative research sites were purposively selected from the quantitative research sampling frame. Research activities were conducted separately with hired laborers and with smallholders. These included sex-disaggregated focus group discussions (FGDs) on four different topics. All four were held with women and three were separately held with men. These were run by facilitators of the same gender. Additional activities included an activity with husband–wife couples, a community profile (mixed gender) and a mungbean value chain analysis (VCA) with additional key informant interviews (KIIs) (mixed gender). Tools were partly based on the GENNOVATE (gender, norms and innovation) research guide.

FGDs 3–5 were applied to both smallholders and hired laborers. FGD 3 asked a couple to reflect individually and then together on their visions for the future. Discussion focused on (gendered) factors hampering or facilitating vision realization. FGD 4 asked respondents to explore the respective abilities of women and men to respond to mechanization through innovating into new livelihoods. FGD 5 asked women to reflect on their sense of empowerment. For smallholders, FGDs 1 and 2 investigated the role of mungbean in the local agricultural system and specifically on their own farm. For hired laborers, FGDs 6 and 7 focused on how they earn a living and the relative significance of mungbean (across production to post-harvest processing) to their livelihoods. Across all FGDs, respondents were asked to reflect on who makes key decisions on the topics discussed. Forces driving system change, and their effects, were explored. To help understand gender norms, and if they are changing, all respondents in every FGD were asked to discuss what gender equality means to them and to provide local examples.

Sampling criteria were as follows: 6–8 respondents per sex-disaggregated FGD. Smallholders had to grow mungbean over the past three years. Hired laborers needed to be landless women and men workers known to regularly participate in mungbean harvesting. Every respondent had to come from a different household, and they were drawn from different locations in each community. Respondents for the community profile (average eight per community, women and men) were expected to be of high standing in the community and to be able to contribute diverse knowledge: for instance, elected village leaders, health- care staff and teachers. The value chain exercise was conducted more opportunistically, with respondents selected on the basis of their known participation in different locations in the mungbean value chain.

Village 1 is in Lower Myanmar. It had 917 households in 2019. Of these, 600 households (around two thirds) were landless and worked as hired laborers. Village 2 in the Central Dry Zone in Myanmar had 214 households in 2019. About one-third (30% = 63 households) worked primarily as agricultural laborers. Village 3 in northern Bangladesh had around 785 households. Of these, 456 households provide hired labor (58%). Village 4 in southern Bangladesh had 687 households in 2019 with 376 providing hired labor (54%) (Depenbusch et al. 2021).

Ex-Ante Partial Budget Analysis

To calculate the likely impact of mechanized harvesting on farm incomes and labor demand, we combined the survey data on mungbean production with a set of assumptions. These were partially based on the experience of mechanization in the rice harvest, which provides a local example of the mechanized harvesting of a field crop. Since mungbean is usually harvested in one to three (but occasionally as many as five) hand-pickings, farmers adopting machine harvesting may opt to conduct one or two pickings by hand before using a combine harvester for the last picking. This decision represents a tradeoff for farmers: an increased number of harvests raises labor costs but also yields, since more pods are allowed to ripen, thus reducing losses. We assessed this tradeoff using a scenario approach assuming one, two or no hand picking and one machine harvest. For simplicity, we ignored effects mediated through changes in the growing period, the speed of the harvest, prices or the area planted. We calculated the hypothetical production cost, yield and profit for each season and aggregated the results to a single observation per household. We then assessed the effect of mechanization on yield by estimating a model with crop yield as dependent variable and the number of pickings as independent variable while controlling for other influencing factors. These include region effects, planted area, length of the growing period (i.e., the time from planting to the last harvest), fertilizer expenditures and pesticide expenditures. We included squared terms for all continuous variables to allow for non-linear relations. The number of harvests was entered as a set of dummies for which we estimated semi-elasticities, which were used as proportional yield reductions under the three scenarios. We used the same controls to estimate the effect of a reduction in harvesting frequency on the share of the total yield harvested in the mechanized harvest, compared to possible earlier hand pickings. This was done separately for households that harvest at least two and three times. We assumed that 10% of the value of the mungbean share harvested mechanically is lost due to seed losses, grain breakage and other effects of combine harvesting. Hence, we estimated the value of mungbean as:

$$Y^S = \begin{cases} (Y^M * (1 - P^s H) * (1 - L * C_S), & H > S \\ Y^M * (1 - L * C_S), & H \leq S \end{cases}$$

Where, Y^S is the yield in scenario S, Y^M is the observed yield, P^sH is the yield penalty for reducing harvest frequency from H to S, L is the yield penalty for seed losses and breakages and C_S is the share of the yield produced in the mechanized harvest. Our assumptions on labor reductions and rental cost of combine harvesters were based on the use of combines in the monsoon rice harvest in Myanmar. First, we considered that a reduced number of harvests affects the total labor requirement, even without mechanization. We based the size of this effect on a regression of the total labor requirement on the harvesting frequency and controls. To account for the non-normal distribution of the variables, we used a log-log specification. As controls, we added the planted area, yield, the length of the crop cycle and seasonal and regional effects. Based on a comparison of the model fit, only the planted area was also entered as squared term. We transformed the resulting coefficient into estimates of the relative impact. Second, we assumed that the labor hours of each person group participating in the harvest are equally divided over the number of harvests. Third, the labor reduction in the mechanized harvest was calculated as the relative change in the average quantity of labor required by farmers who use a combine harvester in the rice harvest, compared to what they estimated to have required for a hand harvest. This was done separately for men and women of the farming family and hired men and women. We combine the assumptions on the labor-saving effects by calculating

$$L^S_g = \begin{cases} L^M_g * F^S_H * (1 - \frac{Rg}{S}), & H > S \\ L^M_g * (1 - \frac{Rg}{H}), & H > S \end{cases}$$

Where LSg is the time group g works in the mungbean harvest if harvest number S is mechanized. LMg is the labor currently required, F^SH is the estimated reduction due to a reduction from H to S harvests and Rg is the ratio of labor remaining for group g in the mechanized rice harvest. We assumed that labor cost, including in-kind provisions, increase at the same rate as the labor hours. Besides changes in the labor cost, we assumed that the production cost increases by the average rental cost for a combine harvester in the rice harvest. As we can only observe mechanization in the rice harvest in Myanmar, we assumed that relative effects on labor and the absolute rental cost of the combine is the same in both countries and that they rise proportionally with the planted area. With mechanization likely to require the application of an herbicide or plant growth regulator for desiccation, we added the average cost of an herbicide application observed in our sample of mungbean farmer.

6 Achievements against activities and outputs/milestones

6.1 Develop a package of cropping practices to facilitate mechanical mungbean harvesting, including safe and effective use of crop desiccants.

No.	Activity	Outputs/ milestones	Completion date	Comments
1.1	Identify the current farming practices in each country that impact harvestability	Report on the practice changes to be promoted in each country; 1 Y	30 June, 2018	In Myanmar, there was concern in the use of chemical desiccants for harvesting, particularly for the sprout industry.
1.2	Assess international and national experiences in the use of crop desiccants	Report on the current status of the use of desiccants; 6 M	30 December, 2018	An exploratory survey was performed to know the different types of chemical desiccants both from a literature search and scientific community experiences. The same exercise was also initiated with other partner countries to obtain the list of available safe chemicals which are under commercial use.

1.3	Study the effect of selected desiccants on seed residues and germinability	Report on the preferred desiccant(s) and their application methods and affect 2 Y A research publication in a high impact journal; 4Y	Summer 2017 & 2018 at Hyderabad, India 2018-2021 at Bangladesh, Myanmar and Pakistan	A preliminary study was conducted at the WorldVeg South Asia site, Hyderabad with 8 different desiccants (Glyphosate, Paraquat, Ethrel/ethephon, Thiourea, $MnCl_2$, and Sodium Cacodylate, DROPP (synthetic BA) with two dosages in two seasons (spring and *kharif* 2017). The preliminary study indicated that each desiccant has differential response and is concentration dependent. Among them, Paraquat and Glyphosate were found effective. Paraquat could desiccate plants in 24 to 48 h (grey to blackish grey). Glyphosate does the same job in 5 days (same is true with Sodium Cacodylate & DROPP) during spring season. Ethrel with higher dilutions (500 times) gave a better response than with 250 times (advantage is drying and defoliation simultaneously, in 3-4 days). Residue analysis done in seeds found no chemical residues of the tested desiccants. Based on field experiences and considering the safety aspects it was decided to use a few among these chemicals (depending on the availability in each partner country, without Paraquat). Field layouts along with data sheets were shared by WorldVeg with the partners in Bangladesh and Pakistan. In Bangladesh and Pakistan, four desiccants (Glyphosate, Ethrel, Urea and Thiourea) and in Myanmar, three desiccants (Glyphosate, Ethrel and Urea) with two dosages were investigated. In Bangladesh, experiments were commenced at two locations. Desiccants were sprayed when pods were 80-85% dried at the Irshudi site, while heavy rain prevented any operation at the Gazipur site. Data collation is in progress In Myanmar, due to heavy rains the team was unable to conduct any spray activities, though the plots were ready in Yezin. Planning is underway for two new trials in July 2018 at Tatkon and Sebin. In Pakistan, the study has been initiated at two locations, Plots will be ready for desiccant spraying by early September 2018. Desiccants were applied when 80-85% mungbean pods dried. The chemicals

				other than Glyphosate in target countries showed the following results: Bangladesh: Thiourea (10%) dried down the leaves in 8-9 days, though Glyphosate achieved it within 5 days. Myanmar: Ethrel (0.5%) gave better leaf drying effect on 6th day compared to urea. Pakistan: Thiourea (10%) showed better result than other desiccants. However, in all these countries, mungbean plants treated with Glyphosate showed early foliage drying (5-6 days). Overall, chemicals used as desiccants, didn't pose any threat on seed yield, coloration & germination. The seed samples harvested from field trials (3 countries) were sent to a globally accredited analytical lab (Eurofins Pvt Ltd) in India, for chemical residue. The seed samples harvested from field trials (3 countries) were analysed for chemical residue. Out of 130 (60-Pakistan, 30-Bangladesh & 40-Myanmar), 40-45 samples were used for each desiccant. No traces of chemicals were detected in the seed samples, except in 9 samples. In these samples traces of Glyphosate higher than the permissible limit was observed. In Bangladesh (Ishwardi site) thiourea (10 and 15%) was the most effective desiccant followed by Glyphosate (0.5%) and Glyphosate (0.5%) in combination with Ammonium Sulphate (1%). Desiccant trial was sown at Ishwardi site on 8 April, 2020. In Myanmar, in the experiments conducted in both Sebin and Yezin sites, Glyphosate (0.5%) alone and in combination with Ammonium Sulphate (1%) showed accelerated desiccation of leaves (4 days), followed by Ethrel (0.5%) (6-7 days) and Urea (10%) (7 days). Desiccant trial was sown at Yezin site in June, 2020. In Pakistan (Islamabad site) there was no significant difference in the number of days for drying of the leaves among the desiccants used (Glyphosate, Glyphosate plus Ammonium Sulphate, Ethrel and Thiourea), except urea. Desiccant trial for the season 2020 was sown at Bhakkar site in May 2020. **Pakistan:** Four desiccation trials were conducted during 2018-2021 at Bhakkar and Islamabad locations using a popular variety NM 11 . The

				treatment Glyphosate (1%) followed by Thiourea (100g) and Glyphosate 1 (0.5%) with significant difference between them at Bhakar and a non-significant difference at Islamabad were the most effective for leaf dryness among nine treatments at Bhakar and Islamabad locations during 2018. These two treatments had a significant difference with untreated control and water spray for leaf defoliation at Bahkar during 2018. There was a non-significant difference among treatments for seed yield. The treatments, Ethrel 1 (0.5%), Ethrel 2 (1.0%), Glyphosate (0.5%) + Ammonium sulfate (1%), Glyphosate 1 (0.5%), Thiourea (10%), and Thiourea (15%) reported with almost similar effect on leaf dryness at Islamabad during 2019. All these treatments except between Glyphosate (0.5%) + Ammonium sulfate (1%) and Glyphosate 1 (0.5%) had non-significant difference for leaf defoliation. These treatments were significantly superior over untreated control, Urea (10.0%) and Urea (12.5%). There was no significant effect of these chemical treatments reported on seed yield at Islamabad during 2019 (Table 5). Similarly, the treatments i.e. Glyphosate (0.3%) + Ammonium sulfate (1%), Glyphosate (0.5%) + Ammonium sulfate (1%), and Thiourea (15%) were found to be equally effective (4.32 to 5 score for leaf dryness) with the non-significant difference among them for leaf dryness at Islamabad during 2020. Of these, Glyphosate (0.5%) + Ammonium sulfate (1%) and Thiourea (15%) had non-significant differences for leaf defoliation. There was a non-significant difference among treatments for seed yield at Islamabad during 2020. The chemical residue analysis of seed samples from trials conducted during 2018 revealed that all the samples across treatments complies EU standards except three out of 24 samples tested for Glyphosate residue. **Myanmar:** Eight chemical desiccation trials were conducted at Tatkone (2 trials), Yezin (3 trials) and Sebin (3 trials) locations of Myanmar from 2018 to 2021 using popular mungbean varieties Yezin 11 and Yezin 14 . The chemical treatment Glyphosate (0.3%) + Ammonium sulphate (1%) and Glyphosate (0.5%) + Ammonium sulphate (1%) were found to be equally effective with a desiccation score of 5 at Sebin during 2020 and 2021. Another two treatments Ethrel (ethephon) (0.5%) and Urea (10.0%)

				were also superior over control with a desiccation score of 4 at Sebin 2020 and 2021. There was no effect on seed discoloration reported at Sabin. The treatments Glyphosate (0.5%) + Ammonium sulfate (1%) and Glyphosate (0.3%) + Ammonium sulfate (1%) dried down the whole plants in 4 and 5 days, respectively compared to Urea (10%) (9 Days). Similarly, these two treatments were also reported superior with a desiccation score of 5 compared to the control (score of 1) at Yezin during 2020 and 2021. At Tatkone during 2018, Glyphosate (1%) followed by Glyphosate (0.5%) reported superior for whole plant drying in 7 and 8 days respectively compared to control (13 days) and water spray (14 days). There was non-significant difference among Glyphosate (0.5%), Glyphosate (1%), and Urea 2 (5%) for leaf defoliation at Tatkone during 2018. The treatments Glyphosate (0.3%) + Ammonium sulfate (1%), Glyphosate (0.5%) + Ammonium sulfate (1%), and Urea (10.0%) were found to be equally effective for pod drying within 3 days after application compared to control at Tatkone 2020. **Bangladesh:** Seven desiccation trials were conducted in Bangladesh at Ishwardi (2 trials), Gazipur (2 trials), Rangpur (2 trials) and Madaripur (1 trial) from 2018 to 2021 using two popular varieties viz., BARI Mung 6 and BARI Mung 7. The chemical treatments Thiourea (10%) and Thiourea (15%) (score of 4.66) followed by Glyphosate 0.3% + 1% Ammonium sulfate, Glyphosate 0.5% + 1% Ammonium sulfate (score of 3.65) and Ethrel (ethephon) (1.0%) (score of 3.00) reported superior over control for leaf dryness with non-significant different among them at Ishwardi during 2019. Also there was no significant effect of these chemicals noticed on seed yield and leaf defoliation per ha at Ishwardi. Similarly, Thiourea (10%) and Thiourea (15%) (score of 4.66) were found equally effective followed Glyphosate (0.5%) and Glyphosate 0.5% + 1% Ammonium sulfate, Ethrel (ethephon) (0.5%), and Ethrel (ethephon) (1.0%) with non-significant differences among them for lead dryness at Gazipur and Rangpur during 2019. These treatments significantly differed with Urea (10.0%), Urea (12.5%) and Untreated dry control for leaf dryness, leaf defoliation and seed discoloration across Gazipur and Rangpur during 2019. A slight effect of these treatments on seed discoloration with

No.	Activity	Outputs/ milestones	Completion date	Comments
				a score ranging from 2.11 to 2.48 was reported compared to untreated control (0.97) at Gazipur and Rangpur during 2019. There was no significant effect of these chemical treatments on seed yield. The treatment, Thiourea (15%) recorded higher leaf dryness score (4.66) at Gazipur and Rangpur during 2021 whereas Glyphosate 0.3% + 1% Ammonium sulfate recorded a higher leaf dryness score (4.00) at Madaripur 2021 (Table 11 & Figure 5). There was non-significant difference among Ethrel (ethephon) (1.0%), Glyphosate 0.3% + 1% Ammonium sulfate, Glyphosate 0.5% + 1% Ammonium sulfate and Thiourea (15%) for leaf dryness across three locations during 2021.

6.2 Develop the most effective and economic mungbean harvesting method suited to Bangladesh, Myanmar and Pakistan.

	Activity	Outputs/ milestones	Completion date	Comments
2.1	Rapid value chain analysis	Report on description of local systems and markets; 1 Y	November 2020	Data collection was done in September 2018 in Bangladesh and in March 2019 in Myanmar. Completed

2.2	Identify existing cereal harvesting practices in each country and key co-operators	Report on existing cereal harvesting practices in the three countries; 6 M, at least 5 collaborating farmer fields identified for demonstration; 1 Y	November 2021	In both Bangladesh and Myanmar, the cereal harvesters currently being used are too aggressive for harvesting mungbeans. During our ACIAR project annual meeting at Dhaka (11-13 Feb 2019), it was discussed and decided to make use of various makes of harvesters available in each partner country (for eg; Yanmar, Kubota & Claas in Myanmar; Yanmar, Daedong & KYM machineries, in Bangladesh; New Holland machines in Pakistan) with specified modifications as per Mr. Xavier's advice. As a convenient practice, it was collectively agreed to use 1% Glyphosate (at least for 2019 season) as desiccant, prior to machine harvesting. The project team had also visited ACI Motors Ltd, Dhaka and discussed details with the staff and invited them to be a part of the project and test a few of their harvesting machines (models) on our experimental trials and farmers' fields. ACI has agreed to work with BARI project team (seasons of 2019) to showcase its combine (harvesters) capabilities suitable for mungbeans for future potential field application on a larger scale. In Bangladesh, BARI-Pulses Research Centre would need to own the selected machine to facilitate trials, organise farmers' demonstration without relying on ACI to lend a machine. The purchase could be partly funded by the project if additional funds can be raised from BARI. In June 2020, BARI has identified JEILONG 4LZ-4L Combine Harvester for conduct of the harvesting trials. In Myanmar, Kubota model with the bean kit is being used. In Pakistan, Glyphosate-desiccated crops could be harvested well with a tuned harvester but for the broken seed. New Holland machine and much bigger machines were used for wheat and rice and now for mungbeans. With changes to the settings as suggested by Mr. Xavier Martin (Consultant from Australia), better results were obtained in 2019. Hubs with machines are now available for mungbean harvesting. In Pakistan, significant progress has been made in modifying New Holland TC 5040 Harvester in reducing seed losses and NARC is actively promoting mechanical harvesting through farmer organisations. In Myanmar, harvest hubs have been formed and are actively using Kubota DC 70 G fitted

	Activity	Outputs/ milestones	Completion date	Comments
				with bean kits for hiring by farmers. BARI has teamed up with ACI Motors Ltd and will promote the use of Yanmar YH – 700 for mungbean harvesting.

2.3	Trial combine harvesting and other methods with progressive farmers and harvesting contractors and establishing community based agri-enterprise for harvesting services to small holder farmers.	At least 20 ha of demonstration area covered in each of the targeted district in Bangladesh and Myanmar every year; 1-4 Y, Report on the effect of harvesting on the quality of grain; 1-4 Y, Local harvesting hubs established in each of the targeted districts in Bangladesh and Myanmar; 3-4 Y A research publication in a high impact journal; 4 Y	.	In Bangladesh, attempts to harvest the experimental trial were not successful due to the incompatibility of the harvesting machine available at Ishrudi. In Myanmar, a harvesting trial was successfully conducted at Yezin. During 2018 season, existing cereal harvester/s and its modified versions were employed to harvest mungbean crop with and without desiccant application. In Myanmar, harvesting trials were successfully conducted in Tatkone and Sabin sites. Cereal harvester (Kubota, DC 70-G) and modified Kubota (suit to mungbean harvesting) were used in these trials. Yield loss of 9.5-10% was observed compared to manual harvesting. Efforts are underway to address the issues of reducing the yield loss, accessing to machine harvest during rainy season and in rice fallow. Overall, the machines were proved to be useful in saving the harvest time and labour. In Pakistan, trials were conducted in Islamabad & Bhakkar locations, with existing and modified cereal harvester (New Holland, TC-5040) (Fig. 4). Modification in terms of drum speed (reduced from 850 to 650 rpm), fan speed (increased from 800 to 1000 rpm) was effected. Seed loss of 12-13% was observed with both existing and modified harvesters, irrespective of the use of Glyphosate, compared to 8% (manual harvested). This was discussed during the annual meeting and it was suggested that a few more improvements of the harvesters were are required for reducing the losses. Efforts are also need to be streamlined to reduce the damage and seed split. In 2019 season, 5 ha area planted as demonstration plots in Bhakkar and Chakwal districts to demonstrate mechanized harvesting by involving progressive farmers and harvesting contractors. In Bangladesh, the use of Glyphosate as a desiccant resulted in less yield loss (18%) compared to the non-desiccated crop (42%). In Bangladesh (Ishwardi site) hand harvested plots recorded significantly higher seed yields compared to the cereal harvesters (regular and modified) with/without Glyphosate. Harvesting trial was sown in Ishwardi site on 8 April, 2020. In Myanmar (Sebin site), seed yield from plots harvested by use of modified Kubota machine with or without

				Glyphosate were significantly lower compared to hand harvested ones. Also, seed losses from the use of modified Kubota machine with or without Glyphosate were significantly higher (about 3 times) compared to hand harvesting. The trial conducted at Tatkone Research Farm was sown during March 2020 and harvested in the first week of June 2020 (beginning of the rainy season). The variety used for the trial was Yezin 14. The results showed that there was no significant difference in the seed yield between the different treatments. However, there was significant seed loss by machine (Kubota with bean kit) harvesting alone compared to the other methods. The percentage of breakage in the seed was the least in the machine harvesting method. The trial conducted in a farmer field in Yangon was sown during November 2019 and harvested during the dry season of February 2020. The variety grown by the farmer was Yezin 9. The results showed that there was no significant difference in the seed yield between the different treatments. Machine harvesting alone (Kubota with modifications) had the least seed loss, followed by manual harvesting (twice) plus machine harvesting. However, the seed breakage percentage was the least by manual harvesting (twice), followed by machine harvesting alone. There was no difference in the germination of the harvested seed between the different treatments. In Pakistan, trials were conducted in NARC Islamabad, with existing and modified cereal harvester (New Holland, TC-5040). Modification in terms of drum speed (reduced from 850 to 650 rpm), fan speed (increased from 800 to 1000 rpm), top and bottom sieve opening (decreased 25 to 25 and 28 to 10 respectively) was effected. Seed loss of 6% was observed with both existing and modified harvesters, irrespective of the use of Glyphosate, compared to 7.4% (manual harvested). Seed loss reduced from 12 to 6% as compared with last year results. Percentage of broken seed was also reduced from 22 to 19%. In 2019 season, 10 demonstration plots (0.4 ha each) was sown at farmers' fields in Bhakkar and Chakwal districts to demonstrate recommended production technology and mechanized harvesting by involving progressive farmers and harvesting contractors. Three tonnes of seed were produced in collaboration with PARC and Agro. Tech

				CO. Harvesting was done using New Holland harvester. Harvesting trial and 10 demonstration plots have been sown in June 2020 at Bhakkar site and sowing is in progress at Chakwal and Islamabad sites.
			November 2021	**Pakistan:** Older models of New Holland combine harvesters operating in Pakistan are 8060, 8070, TC-55, TC57, TC56, 1540, 1550, Semeca and Leverda). Old model combine owners in country mostly used fixed pulleys in combine threshing drum drive system which makes it difficult to lower the threshing drum speed. With New Holland combine harvesters it is possible to have adjustable drum speed, reel speed, sieves and blower/fan speed. Hence the decision was made to identify a New Holland harvester This trial was conducted at NARC, Islamabad, with existing and modified cereal harvester (New Holland, TC-5040). Modification in terms of drum speed (reduced from 850 to 650 rpm), fan speed (increased from 800 to 1000 rpm) was effected. Three mechanical harvesting trials were conducted during 2019-2021 at Islamabad using two popular varieties i.e. NM 11 and NM 16. The results revealed that there was no significant difference among the treatments i.e. manual (traditional) harvesting, using cereal harvester with glyphosate, and using modified harvester without glyphosate for seed yield. However, all the treatments using harvesters had a significant difference with traditional harvesting for % broken seeds at Islamabad 2018 and 2019. The highest % broken seeds was recorded for treatment cereal harvester without glyphosate (27%) followed by cereal harvester with glyphosate (23.68-25.59%), modified harvester without glyphosate (24%), and modified harvester with glyphosate (19.22 to 20.74%) in comparison with manual harvesting (7.3 to 9.1%). There was no significant difference among the treatments for % discolored seeds and %seed loss at Islamabad 2018 and 2019. No significant difference among the treatments was recorded for seed yield at Islamabad during 2020 (Table 18). However, there was significant difference among all the treatments for %broken seeds and % whole seeds. Hand picking combined with mechanical harvesting (with desiccant) resulted in lower % of broken seeds and % seed loss compared to sole mechanical harvesting.

				Myanmar: The DAR Agricultural Mechanisation Department (AMD) fleet is in majority made up of Kubota DC 70 G harvesters configured for cereal harvesting. The AMD district depot held stock in the part store that included the components comprising the factory supplied edible bean modification kits to suit Kubota DC 70 G harvesters which make up the majority of AMD's relatively extensive harvester fleet. In discussion with the Department and Depot Management it was apparent that the subject Kubota DC 70 G harvester was scheduled to have the edible bean kit fitted during the current harvester refurbishment program, presenting a significant opportunity for improvement in mungbean harvesting. Seven mechanical harvesting trials were conducted at Tatkone (3 trials), and Sebin (4 trials) locations of Myanmar from 2018 to 2021 using popular mungbean varieties Yezin 11 and Yezin 14. There was a non-significant difference between hand harvesting (farmer's practice) and modified harvester with desiccant) and modified harvester without desiccant for seed yield at Sebin during 2018 whereas it was a non-significant difference among all the treatments for seed yield and %seed loss at Tatkone during 2018. There was a significant difference among the treatments hand harvesting with modified harvester with and without desiccant for seed yield and %seed loss at Sebin during 2019. The seed loss of around 56.82% was noted when modified harvester was used with desiccant followed by Modified harvester without desiccant (48%) compared to hand harvesting (11%) at Sebin during 2019. At Tatkone during 2019, Hand harvesting (farmer's practice) and Modified harvester without desiccant have non-significant differences for seed yield. All the treatments had significant differences for % broken seeds, %discolored seed and %seed loss. The highest %broken seeds recorded in Modified harvester with desiccant (9.50%) followed by Modified harvester without desiccant (6.43%) compared to hand harvesting (0.41%). The highest %seed loss was recorded in modified harvester with desiccant (35.02%) followed by Modified harvester without desiccant (10.47%) compared to hand harvesting (7.06%) at Tatkone during 2019. Contrastingly, there was a non-significant difference observed among treatments for seed yield and % seed loss at Sebin during 2020. However, a significant difference among the treatments was recorded for %seed loss at Sebin 2021. The highest %seed

	Activity	Outputs/ milestones	Completion date	Comments
				loss recorded for treatment only mechanized harvest with desiccant (22.30%) followed by 1 hand picking + mechanized harvest with desiccant (16.92) with non-significant difference among them. There was a non-significant difference among the treatments for seed yield at Tatkone during 2020 whereas the differences were significant for % seed loos and %broken seeds. The highest %seed loss was recorded in only mechanized harvest with desiccant (18.51%) followed by 1 hand picking + mechanized harvest with desiccant (10.62%) and 3 hand pickings (9.96%). **Bangladesh:** One mechanical harvesting trial was conducted in Bangladesh at Ishwardi during 2019 using two popular variety BARI Mung 7. The results revealed that there was a significant difference among the treatments for seed yield at Ishwardi during 2019. The highest seed yield was recorded in hand harvesting (1267 kg/ha) followed by treatment modified JEILONG 4L-BZ 110 KYM machinery with Glyphosate (1%) (846 kg/ha) and modified 4L-BZ 110 KYM machinery without Glyphosate (751 kg/ha). The treatment of hand-harvesting (farmer practice) had a significant difference with other machine harvesting treatments for %broken seeds, %discolored seeds, and %whole seeds. The highest % seed loss was recorded in Modified Daedong with Glyphosate (1%) (21.10%) followed by Modified Daedong - without Glyphosate (15.74%) compared to hand harvesting (9.75%).
2.4	Identify international and national best practices to trial	Review of literature and linking with national and international experts	November 2021	Mr. Xavier Martin, an experienced mungbean farmer from Australia for assessing the status of harvesters in Bangladesh, Myanmar and Pakistan and for his recommendations on the suitable ones for mungbean harvesting.
2.5	Produce videos and information packages on how to best harvest mungbeans mechanically	Case studies; training of both seed and grain producers	November 2021	Videos on mechanical harvesting of mungbeans developed in Myanmar and Pakistan

	Activity	Outputs/ milestones	Completion date	Comments
2.6	Develop a business model for harvesting services	Economic & social analysis	November 2021	In Pakistan, PARC and Agro. Tech CO are working together in facilitating mechanical harvesting of mungbean for seed production. In Myanmar, harvest hubs have been formed from where farmers are able to hire harvesters for mungbean harvesting. In Bangladesh, BARI has purchased YH 700 (YANMAR) model harvester from ACI Motors Ltd for promotion of mechanical harvesting of mungbeans.
2.7	Communicating policy implications of project results to senior officials and decision makers	Qualitative analysis	November 2021	The document will be shared with policy makers to support their decision-making
2.8	Investigate on the genetics, physiological and molecular mechanisms of the leaf senescence trait at pod maturity	Understanding the genetics of the leaf senescence trait through genetic analysis; Phenotyping for leaf senescence including physiological traits; QTLseq analysis to understand molecular mechanism and identifying candidate genes for leaf senescence trait	November 2021	Populations have been developed with the leaf senescence trait and preliminary results indicate that the senescence trait is controlled by a single dominant gene. This activity will be continued in the IMIN2 project.

6.3 Communicate the likely impact of a change in harvesting practices on women to all stakeholders and provide management options that would potentially benefit the livelihoods of women (In all three countries).

No.	Activity	Outputs/ milestones	Completion date	Comments
3.1	Build capacity among national partners to conduct quantitative and qualitative gender research	3 workshops held and at least 4 researchers intensively trained with others attending some of the workshops	November 2020	Dr. Cathy Farnworth was hired as a qualitative gender consultant to support the project. The first workshop was held in Nay Pyi Taw, Myanmar on 23-26 January 2018. The team from Yezin Agricultural University (YAU) participated in the workshop “Developing inclusive business model in Mungbean” with ICCO Cooperation on 21-22 February in Yangon and the ACIAR gender awareness workshop in Nay Pyi Taw on 12-13 June. A training on the use of electronic data collection software was done on 26 June 2018 for the team at YAU and other interested university members. The team of YAU had a training on the collection of qualitative data in February 2019, while the team in Bangladesh had the same training in March 2019. In February 2019 preliminary findings were discussed during the annual meeting in Dhaka. Due to bureaucratic problems the team of YAU was not able to participate. In May and June 2020 two scientists from Bangladesh and one scientist from Myanmar were introduced (by WorldVeg) to the coding of qualitative data, which they then applied to their data sets. One scientist of YAU was actively involved in the analysis of the quantitative data, including the analysis of complex survey data with the statistical software package STATA.
3.2	Identify the current role of women in mungbean harvesting and assess the likely impacts of mechanical harvesting on their livelihood. Assess this as a part of the farm household surveys in Myanmar and Bangladesh	Quantitative survey; 1Y Qualitative survey; 2Y 2 Scientific publications written; 3Y & 4Y	December 2020	Detailed protocols and data collection instruments were developed for the quantitative and qualitative components of the study. The quantitative survey was conducted in Myanmar in July 2018 and in Bangladesh in February 2019. The qualitative survey was conducted in Bangladesh during March and April 2019 and in Myanmar in February 2019. In Pakistan, this had been conducted and reported under GiZ/WorldVeg project Beans with Benefits in 2018. Depenbusch L, Farnworth CR, Schreinemachers P, Myint T, Islam MM, Kundu ND, Myint T, San AM, Jahan R, Nair RM. 2021. When Machines Take the Beans: Ex-Ante Socioeconomic Impact Evaluation of Mechanized Harvesting of Mungbean in Bangladesh and Myanmar. Agronomy 11, 925. https://doi.org/10.3390/agronomy11050925

No.	Activity	Outputs/ milestones	Completion date	Comments
3.3	Explore how women can engage in and benefit from the business models for harvesting services	1 Report or scientific publication written and integrated with Activity 2.6	December 2020	Data collected as part of Activity 3.2 Farnworth CR, San AM, Kundu ND, Islam MM, Jahan R, Depenbusch L, Nair RM, Myint T, Schreinemachers P. 2020. How Will Mechanizing Mungbean Harvesting Affect Women Hired Laborers in Myanmar and Bangladesh? Sustainability 12, 7870.

7 Key results and discussion

7.1 Chemical Desiccation Experiments:

The analysis of variance (ANOVA) revealed significant differences among the treatments for traits such as seed yield per ha, leaf defoliation, leaf dryness and desiccation score at most of the locations indicating the differential response of chemical desiccants on dry down process in mungbean.

India: Different desiccation chemicals were tested at the start of the project at Hyderabad to standardize the experimental protocols and traits during 2017-18. Among the eight chemical treatments, Urea @ 12.5%, Urea @ 15 %, and Urea @ 10.0% with 76.99%, 76.82%, and 65.49% desiccation, respectively at 7th day were found to be equally effective over different concentrations of Ethephon and Ethrel (Table 5). The initial experiments conducted at Hyderabad were useful in formulating the chemical treatments and experimental procedure.

Table 5. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at Hyderabad, India during 2018.

No	Treatment	Pod yield per plot (g)	Seed Yield per plot (g)	Percent Desiccation (Day 7)	Percent Desiccation (Day 10)
1	Ethephon @ 5 ml / 1 ltr water	847	555	37.40[b]	52.13[b]
2	Ethrel @ 4 ml / 1 ltr water	885	564	3.01[c]	5.15[c]
3	Ethrel @ 5 ml / 1 ltr water	879	585	39.09[b]	47.90[b]
4	Ethrephon @ 6 ml / 1 ltr water	866	581	36.56[b]	43.26[b]
5	Urea @ 10.0%	932	624	65.49[a]	75.71[a]
6	Urea @ 12.5%	959	637	76.99[a]	88.86[a]
7	Urea @ 15 %	721	475	76.82[a]	83.40[a]
8	Urea @ 7.5%	620	396	38.32[b]	43.33[b]
9	Dry control	838	563	0.01[c]	0.01[c]
10	Wet control	1008	651	0.01[c]	0.01[c]
	CV (%)	15.78	16.83	16.17	15.74
	SEM±	77.95	54.75	0.06	0.06

Pakistan: Four desiccation trials were conducted during 2018-2021 at Bhakkar and Islamabad locations using a popular variety NM 11 (Table 1). The treatment Glyphosate (1%) followed by Thiourea (100g) and Glyphosate 1 (0.5%) with significant difference between them at Bhakkar and a non-significant difference at Islamabad were the most effective for leaf dryness among nine treatments at Bhakkar and Islamabad locations during 2018 (Table 6 & Figure 7). These two treatments had a significant difference with untreated control and water spray for leaf defoliation at Bahkar during 2018. There was a non-significant difference among treatments for seed yield. The treatments, Ethrel 1 (0.5%), Ethrel 2 (1.0%), Glyphosate (0.5%) + Ammonium sulfate (1%), Glyphosate 1 (0.5%), Thiourea (10%), and Thiourea (15%) reported with almost similar effect on leaf dryness at Islamabad during 2019. All these treatments except between Glyphosate (0.5%) + Ammonium sulfate (1%) and Glyphosate 1 (0.5%) had non-significant difference for leaf defoliation. These treatments were significantly superior over untreated control, Urea (10.0%) and Urea (12.5%) (Table 5). There was no significant effect of these chemical treatments reported on seed yield at Islamabad during 2019 (Table 5). Similarly, the treatments i.e. Glyphosate (0.3%) + Ammonium sulfate (1%), Glyphosate (0.5%) + Ammonium sulfate (1%), and Thiourea (15%) were found to be equally effective (4.32 to 5 score for leaf dryness) with the non-significant difference among them for leaf dryness at Islamabad during 2020. Of these, Glyphosate (0.5%) + Ammonium sulfate (1%) and Thiourea (15%) had non-significant differences for leaf defoliation. There was a non-significant difference among treatments for seed yield at Islamabad during 2020 (Table 6).

The chemical residue analysis of seed samples from trials conducted during 2018 revealed that all the samples across treatments complies EU standards except three out of 24 samples tested for Glyphosate residue.

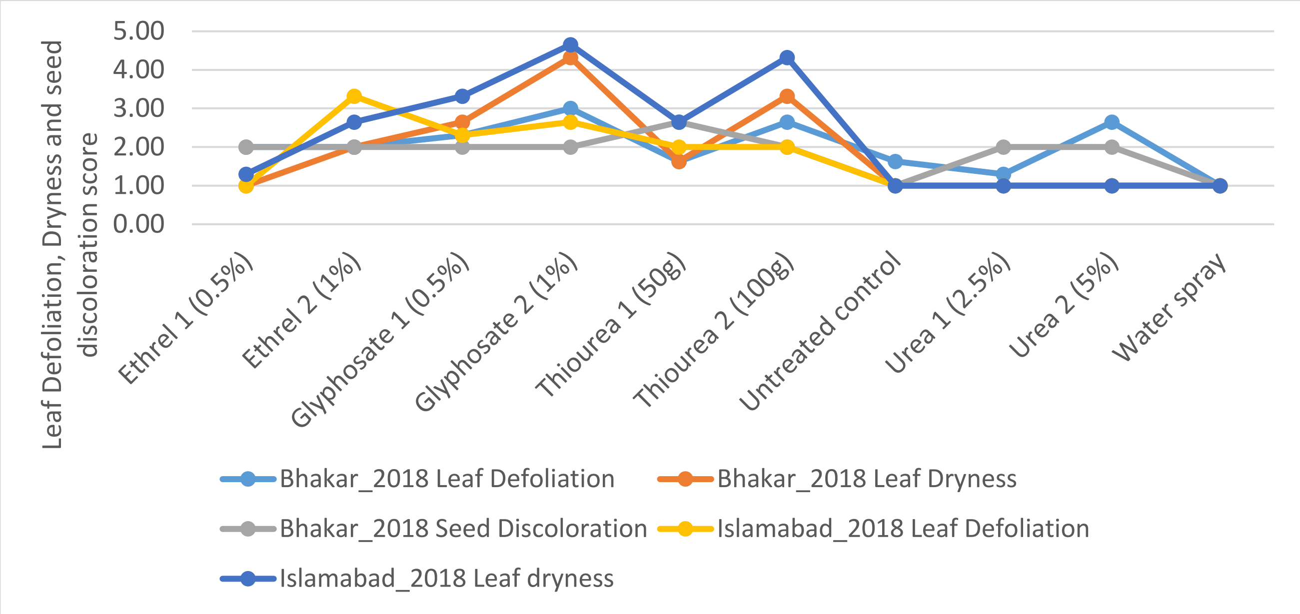

Figure 7. Effect of different chemical desiccants on leaf defoliation, leaf dryness and seed discoloration in mungbean at Bhakkar and Islamabad, Pakistan during 2018

Table 6. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at Bhakkar and NARC Islamabad during 2018

No.	Treatment	Bhakkar 2018				Islamabad 2018		
		Seed yield (kg/ha)	Leaf Defoliation (LD)	Leaf Dryness (LDy)	Seed Discoloration (SD)	Seed yield (kg/ha)	Leaf Defoliation (LD)	Leaf Dryness (LDy)
1	Ethrel 1 (0.5%)	1047	2.00^{bc}	1.00^{d}	2.00^{b}	533	1.00^{d}	1.30^{c}
2	Ethrel 2 (1%)	985	2.00^{bc}	2.00^{c}	2.00^{b}	602	3.32^{a}	2.64^{b}
3	Glyphosat e 1 (0.5%)	1027	2.31^{abc}	2.64^{b}	2.00^{b}	597	2.31^{bc}	3.32^{b}
4	Glyphosat e 2 (1%)	1003	3.00^{a}	4.32^{a}	2.00^{b}	520	2.64^{b}	4.65^{a}
5	Thiourea 1 (50g)	1102	1.63^{cd}	1.63^{c}	2.64^{a}	603	2.00^{c}	2.64^{b}
6	Thiourea 2 (100g)	960	2.64^{ab}	3.32^{b}	2.00^{b}	629	2.00^{c}	4.32^{a}
7	Untreated control	1083	1.63^{cd}	1.00^{d}	1.00^{c}	544	1.00^{d}	1.00^{c}
8	Urea 1 (2.5%)	1040	1.30^{de}	1.00^{d}	2.00^{b}	558	1.00^{d}	1.00^{c}
9	Urea 2 (5%)	1085	2.64^{ab}	1.00^{d}	2.00^{b}	541	1.00^{d}	1.00^{c}
10	Water spray	1103	1.00^{e}	1.00^{d}	1.00^{c}	615	1.00^{d}	1.00^{c}
	CV(%)	5.44	11.08	8.87	4.29	8.84	7.76	9.78
	SEM±	32.78	0.09	0.07	0.07	29.31	0.06	0.08

Table 7. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at NARC Islamabad during 2019

No.	Treatment	Seed Yield (kg/ha)	Leaf Defoliation (LD)	Leaf Dryness (LDy)
1	Ethrel 1 (0.5%)	871.67	3.65^{ab}	4.00^{a}
2	Ethrel 2 (1.0%)	830.00	4.00^{ab}	4.32^{a}
3	Glyphosate (0.5%) + Ammonium sulfate (1%)	853.33	4.32^{a}	4.65^{a}
4	Glyphosate 1 (0.5%)	878.89	3.32^{b}	4.32^{a}
5	Thiourea (10%)	906.11	3.65^{ab}	4.00^{a}
6	Thiourea (15%)	852.22	3.65^{ab}	4.32^{a}
7	Untreated control	901.11	2.31^{c}	1.00^{c}
8	Urea (10.0%)	881.67	2.31^{c}	2.31^{b}
9	Urea (12.5%)	928.89	2.31^{c}	2.64^{b}
	CV (%)	5.10	8.05	7.03
	SEM±	25.86	0.08	0.08

Table 8. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at NARC Islamabad during 2020

No.	Treatment	Seed Yield Per ha (kg)	Leaf Defoliation (LD)	Leaf Dryness (LDy)
1	Ethrel (ethephon) (1.0%)	973	2.00^{bc}	3.32^{b}
2	Glyphosate (0.3%) + Ammonium sulfate (1%)	975	2.31^{b}	4.32^{a}
3	Glyphosate (0.5%) + Ammonium sulfate (1%)	1004	4.32^{a}	5.00^{a}
4	Thiourea (15%)	1017	4.00^{a}	5.00^{a}
5	Untreated control	1021	1.63^{c}	1.30^{c}
	CV (%)	4.17	7.53	5.49
	SEM±	24.02	0.07	0.06

Figure 8. Effect of different Chemical Desiccant Trials at Islamabad and Bhakkar

Figure 9. Field view and harvester being used on the desiccated mungbean field (New Holland).

Myanmar: Eight chemical desiccation trials were conducted at Tatkone (2 trials), Yezin (3 trials) and Sebin (3 trials) locations of Myanmar from 2018 to 2021 using popular mungbean varieties Yezin 11 and Yezin 14 (Table 1). The chemical treatment Glyphosate (0.3%) + Ammonium sulfate (1%) and Glyphosate (0.5%) + Ammonium sulfate (1%) were found to be equally effective with a desiccation score of 5 at Sebin during 2020 and 2021 (Table 9). Another two treatments Ethrel (ethephon) (0.5%) and Urea (10.0%) were also superior over control with a desiccation score of 4 at Sebin 2020 and 2021 (Figure 10). There was no effect on seed discoloration reported at Sabin. The treatments Glyphosate (0.5%) + Ammonium sulfate (1%) and Glyphosate (0.3%) + Ammonium sulfate (1%) dried down the whole plants in 4 and 5 days, respectively compared to Urea (10%) (9 Days). Similarly, these two treatments were also reported superior with a desiccation score of 5 compared to the control (score of 1) at Yezin during 2020 and 2021 (Table 10). At Tatkone during 2018, Glyphosate (1%) followed by Glyphosate (0.5%) reported superior for whole plant drying in 7 and 8 days respectively compared to control (13 days) and water spray (14 days) (Table 11). There was non-significant difference among Glyphosate (0.5%), Glyphosate (1%), and Urea 2 (5%) for leaf defoliation at Tatkone during 2018. The treatments Glyphosate (0.3%) + Ammonium sulfate (1%), Glyphosate (0.5%) + Ammonium sulfate (1%), and Urea (10.0%) were found to be equally effective for pod drying within 3 days after application compared to control at Tatkone 2020 (Table 12).

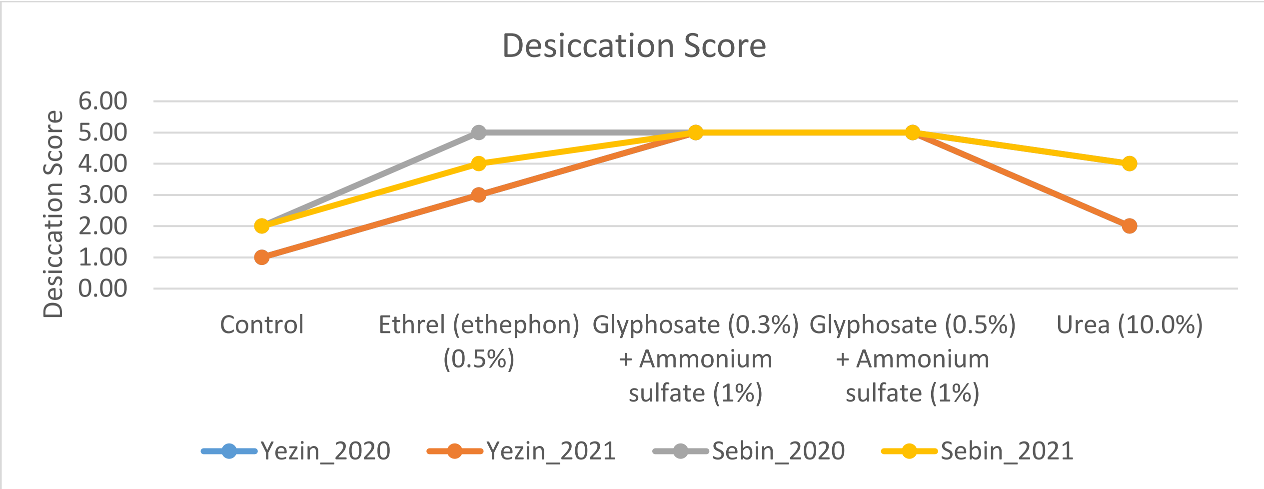

Figure 10. Effect of different chemical desiccants on plant desiccation in mungbean at Sebin and Yezin, Myanmar during 2020 and 2021

Table 9. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at Sebin, Myanmar during 2020-2021.

No	Treatments	Sebin_2020					Sebin_2021						
		Seed Yield (kg/ha)	SD	LD	PD	DS	Seed Yield (kg/ha)	DS	SD	LD	PS	PD (days)	WPD (days)
1	Control	929	1.00	1.00	1.00	2.00	1038[b]	2.00	1.00	1.00	1.00	-	-
2	Ethrel (ethephon) (0.5%)	1125	1.00	1.00	2.00	5.00	1221[a]	4.00	1.00	1.00	1.00	6.00	8.00
3	Glyphosate (0.3%) + Ammonium sulfate (1%)	1087	1.00	2.00	2.00	5.00	1048[b]	5.00	1.00	2.00	2.00	3.00	5.00
4	Glyphosate (0.5%) + Ammonium sulfate (1%)	1255	1.00	2.00	2.00	5.00	937[b]	5.00	1.00	2.00	2.00	3.00	4.00
5	Urea (10.0%)	1253	1.00	1.00	1.00	4.00	1075[ab]	4.00	1.00	1.00	1.00	7.00	9.00
	CV (%)	21.00	-	-	-	-	7.00	-	-	-	-	-	-
	SEM±	137.08	-	-	-	-	45.23	-	-	-	-	-	-

SD - Seed Discoloration; LD - Leaf Defoliation; PD - Pod Drying; DS - Desiccation Score; PS – Pod Shattering; WPD- Whole Plant Drying

Table 10. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at Yezin, Myanmar during 2020-2021.

No	Treatments	Yezin_2020		Yezin_2021	
		Seed Yield (kg/ha)	DS (Day 4)	Seed Yield (kg/ha)	DS (Day 7)
1	Control	415	1.00	622	1.00
2	Ethrel (ethephon) (0.5%)	310	3.00	654	3.00
3	Glyphosate (0.3%) + Ammonium sulfate (1%)	330	5.00	607	5.00
4	Glyphosate (0.5%) + Ammonium sulfate (1%)	318	5.00	618	5.00
5	Urea (10.0%)	384	2.00	533	2.00
	CV (%)	15.54	-	7.76	-
	SEM±	31.52	-	27.20	-

DS -Desiccation Score

Table 11. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at Tatkone, Myanmar during 2018.

No.	Treatments	Seed Yield (kg/ha)	SD	LD	PS	PD (days)	WPD (days)
1	Control	717	1.00	1.00[c]	1.00	12.00	13.67
2	Ethrel (ethephon) (0.5%)	643	1.00	1.00[c]	1.00	8.67	10.67
3	Ethrel (ethephon) (1%)	563	1.00	1.00[c]	1.00	7.67	9.67
4	Glyphosate (0.5%)	563	1.00	2.33[a]	2.00	6.33	8.33
5	Glyphosate (1%)	551	1.00	2.67[a]	2.33	5.67	7.00
6	Urea 1 (2.5%)	532	1.00	1.67[b]	2.00	10.00	12.00
7	Urea 2 (5%)	825	1.00	2.00[ab]	1.67	8.67	10.67
8	Water spray	630	1.00	1.00[c]	1.00	11.67	14.00
	CV (%)	18	-	-	-	-	-
	SEM±	65.29	-	-	-	-	-

SD - Seed Discoloration; LD - Leaf Defoliation; PS – Pod Shattering; PD - Pod Drying; WPD- Whole Plant Drying

Table 12. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at Tatkone, Myanmar during 2020.

S. No	Treatments	Seed Yield (kg/ha)	LD (Days)	PD (days)
1	Control	666	-	7.00
2	Ethrel (ethephon) (0.5%)	457	4.00	5.00
3	Glyphosate (0.3%) + Ammonium sulfate (1%)	470	3.00	3.00
4	Glyphosate (0.5%) + Ammonium sulfate (1%)	537	3.00	3.00
5	Urea (10.0%)	740	2.00	3.00
	CV (%)	26.70	-	-
	SEM±	88.54	-	-

LD - Leaf Defoliation; PD - Pod Drying

Bangladesh: Seven desiccation trials were conducted in Bangladesh at Ishwardi (2 trials), Gazipur (2 trials), Rangpur (2 trials) and Madaripur (1 trial) from 2018 to 2021 using two popular varieties viz., BARI Mung 6 and BARI Mung 7 (Table 1). The chemical treatments Thiourea (10%) and Thiourea (15%) (score of 4.66) followed by Glyphosate 0.3% + 1% Ammonium sulfate, Glyphosate 0.5% + 1% Ammonium sulfate (score of 3.65) and Ethrel (ethephon) (1.0%) (score of 3.00) reported superior over control for leaf dryness with non-significant different among them at Ishwardi during 2019. Also there was no significant effect of these chemicals noticed on seed yield and leaf defoliation per ha at Ishwardi (Table 13). Similarly, Thiourea (10%) and Thiourea (15%) (score of 4.66) were found equally effective followed Glyphosate (0.5%) and Glyphosate 0.5% + 1% Ammonium sulfate, Ethrel (ethephon) (0.5%), and Ethrel (ethephon) (1.0%) with non-significant differences among them for lead dryness at Gazipur and Rangpur during 2019 (Table 14). These treatments significantly differed with Urea (10.0%), Urea (12.5%) and Untreated dry control for leaf dryness, leaf defoliation and seed discoloration across Gazipur and Rangpur during 2019 (Table 14). A slight effect of these treatments on seed discoloration with a score ranging from 2.11 to 2.48 was reported compared to untreated control (0.97) at Gazipur and Rangpur during 2019. There was no significant effect of these chemical treatments on seed yield. The treatment, Thiourea (15%) recorded higher leaf dryness score (4.66) at Gazipur and Rangpur during 2021 whereas Glyphosate 0.3% + 1% Ammonium sulfate recorded a higher leaf dryness score (4.00) at Madaripur 2021 (Table 13 & Figure 11). There was non-significant difference among Ethrel (ethephon) (1.0%), Glyphosate 0.3% + 1% Ammonium sulfate, Glyphosate 0.5% + 1% Ammonium sulfate and Thiourea (15%) for leaf dryness across three locations during 2021 (Table 15).

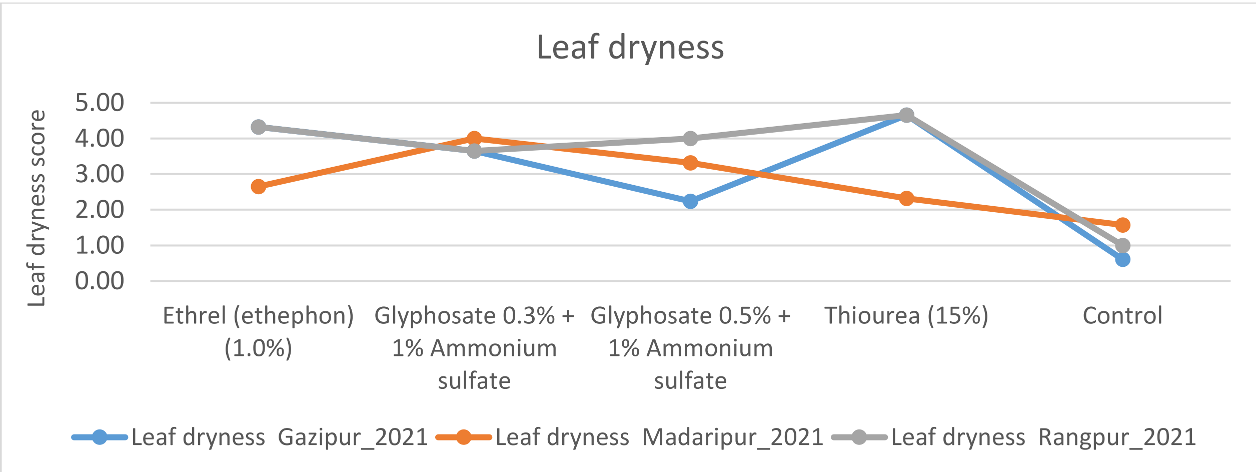

Figure 11. Effect of different chemical desiccants on leaf dryness in mungbean at Rangpur, Madaripur, and Gazipur, Bangladesh during 2021

Table 13. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at Ishwardi during 2019.

No	Treatments	Seed Yield per ha (kg)	Leaf Defoliation	Leaf Dryness	Seed Discolouration
1	Ethrel (ethephon) (0.5%)	974	2.32^{a}	2.32^{bc}	2.94
2	Ethrel (ethephon) (1.0%)	978	2.65^{a}	3.00^{ab}	1.63
3	Glyphosate (0.5%)	986	2.32^{a}	3.65^{ab}	2.64
4	Glyphosate 0.5% + 1% Ammonium sulfate	977	1.64^{ab}	3.65^{ab}	1.63
5	Thiourea (10%)	951	2.65^{a}	4.66^{a}	1.55
6	Thiourea (15%)	941	2.65^{a}	4.66^{a}	1.63
7	Urea (10.0%)	948	0.61^{bc}	1.31^{c}	2.21
8	Urea (12.5%)	947	0.61^{bc}	1.31^{c}	2.31
9	Control	989	0.27^{c}	0.61^{d}	2.31
	CV (%)	6.70	2.82	10.51	17.20
	SEM (±)	37.45	0.14	0.11	0.14

Figure 12. Bangladesh Desiccation Trial at Ishwardi

Table 14. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at Gazipur and Rangpur, Bangladesh during 2019.

No.	Treatment	Gazipur_2019				Rangpur_2019				Combined across locations			
		Seed Yield (kg/ha)	LD	LDy	SD	Seed Yield (kg/ha)	LD	Ldy	SD	Seed Yield (kg/ha)	LD	Ldy	SD
1	Ethrel (ethephon) (0.5%)	906	2.32^{a}	3.96^{ab}	2.31^{ab}	1080^{d}	3.32^{a}	3.65^{a}	2.64^{a}	993^{ab}	2.80^{a}	3.81^{a}	2.48^{a}
2	Ethrel (ethephon) (1.0%)	817	3.32^{a}	3.65^{ab}	1.91^{abc}	1050^{e}	3.00^{a}	4.00^{a}	2.00^{a}	933^{abc}	3.16^{a}	3.83^{a}	1.96 ^{a}
3	Glyphosate (0.5%)	907	2.60^{a}	4.32^{a}	2.64^{a}	1084^{cd}	3.32^{a}	3.96^{a}	2.31^{a}	996^{abc}	2.95^{a}	4.14^{a}	2.48^{a}
4	Glyphosate 0.5% + 1% Ammonium sulfate	853	1.64^{ab}	4.00^{a}	1.63^{abc}	1143^{a}	3.32^{a}	5.00^{a}	2.64^{a}	998^{a}	2.42^{a}	4.49^{a}	2.11^{a}
5	Thiourea (10%)	844	2.32^{a}	5.00^{a}	2.00^{ab}	1122^{b}	3.65^{a}	4.32^{a}	2.64^{a}	983^{abc}	2.95^{a}	4.66^{a}	2.31^{a}
6	Thiourea (15%)	650	2.65^{a}	5.00^{a}	2.31^{ab}	1081^{cd}	3.32^{a}	4.32^{a}	2.00^{a}	866^{bc}	2.98^{a}	4.66^{a}	2.15^{a}
7	Untreated dry control	750	0.61^{bc}	1.64^{c}	1.00^{c}	1100^{c}	0.87^{b}	1.11^{b}	0.94^{b}	925^{abc}	0.74^{b}	1.36^{b}	0.97^{b}
8	Urea (10.0%)	978	0.27^{c}	2.20^{c}	1.30^{bc}	974^{g}	0.61^{b}	0.61^{b}	1.04^{b}	976^{abc}	0.43^{b}	1.32^{b}	1.16^{b}
9	Urea (12.5%)	711	0.61^{bc}	2.52^{bc}	1.30^{bc}	1015^{f}	0.27^{b}	0.50^{b}	1.13^{b}	863^{c}	0.43^{b}	1.37^{b}	1.21^{b}
	CV (%)	18.12	17.04	10.86	16.60	1.07	14.74	16.78	10.16	11.24	15.84	14.40	13.42
	SEM (±)	86.23	0.15	0.13	0.13	6.66	0.14	0.18	0.08	43.24	0.10	0.11	0.10

LD – Leaf Defoliation; Ldy – Leaf Dryness; SD – Seed Discoloration

Table 15. Effect of various chemical desiccants on foliage drying down process and yield in mungbean at Gazipur, Madaripur and Rangpur, Bangladesh during 2021.

No	Treatments	Seed yield per ha (kg)				Leaf Dryness (Ldy)			
		Gazipur	Madaripur	Rangpur	Combined	Gazipur	Madaripur	Rangpur	Combined
1	Ethrel (ethephon) (1.0%)	1187^{b}	1360	1480^{b}	1342^{bc}	4.32^{ab}	2.65^{abc}	4.32^{ab}	3.22^{a}
2	Glyphosate 0.3% + 1% Ammonium sulfate	1237^{b}	1450	1473^{b}	1387^{bc}	3.65^{ab}	4.00^{a}	3.65^{ab}	3.26^{a}
3	Glyphosate 0.5% + 1% Ammonium sulfate	1167^{b}	1370	1440^{b}	1325^{c}	2.24^{b}	3.32^{ab}	4.00^{ab}	2.63^{a}
4	Thiourea (15%)	1233^{b}	1457	1630^{ab}	1440^{b}	4.66^{a}	2.32^{bc}	4.66^{a}	3.32^{a}
5	Control	1547^{a}	1370	1763^{a}	1560^{a}	0.61^{c}	1.57^{c}	1.00^{c}	0.44^{b}
	CV (%)	6.20	8.30	7.50	7.42	12.26	12.30	5.08	14.46
	SEM (±)	46.09	67.53	67.43	35.32	0.13	0.13	0.06	0.19

7.2 Mechanical Harvesting Experiments:

Pakistan: Older models of New Holland combine harvesters operating in Pakistan are 8060, 8070, TC-55, TC57, TC56, 1540, 1550, Semeca and Leverda). Old model combine owners in country mostly used fixed pulleys in combine threshing drum drive system which makes it difficult to lower the threshing drum speed. With recent New Holland combine harvesters it is possible to have adjustable drum speed, reel speed, sieves and blower/fan speed. Hence the decision was made to identify a suitable New Holland harvester. This trial was conducted at NARC, Islamabad, with an existing and modified cereal harvester (New

Holland, TC-5040). Modification in terms of drum speed (reduced from 850 to 650 rpm), fan speed (increased from 800 to 1000 rpm) was effected (Table 16).

Table 16. Harvester Setting (New Holland Combine Harvester TC-5040)

Settings	Cereal	Mungbean		Remarks
	2018/2019	2018	2019	
Reel Speed	Medium	Medium	Medium	
Drum Speed	850 RPM	650 RPM	670 RPM	Modified
Concave type	Cereal	Cereal	Cereal	
Concave Clearance	25 mm	25 mm	25 mm	
Fan Speed	800 RPM	1000 RPM	1000 RPM	Modified
Top Sieve Opening	25 mm	25 mm	15 mm	Modified
Bottom Sieve Opening	28 mm	28 mm	10 mm	Modified

Three mechanical harvesting trials were conducted during 2019-2021 at Islamabad using two popular varieties i.e. NM 11 and NM 16 (Table 2). The results revealed that there was no significant difference among the treatments i.e. manual (traditional) harvesting, using cereal harvester with glyphosate, and using modified harvester without glyphosate for seed yield. However, all the treatments using harvesters had a significant difference with traditional harvesting for % broken seeds at Islamabad 2018 and 2019. The highest % broken seeds was recorded for treatment cereal harvester without glyphosate (27%) followed by cereal harvester with glyphosate (23.68-25.59%), modified harvester without glyphosate (24%), and modified harvester with glyphosate (19.22 to 20.74%) in comparison with manual harvesting (7.3 to 9.1%). There was no significant difference among the treatments for % discolored seeds and %seed loss at Islamabad 2018 and 2019 (Table 17 & 18 see in appendix). No significant difference among the treatments was recorded for seed yield at Islamabad during 2020 (Table 19 see in appendix). However, there was a significant difference among all the treatments for %broken seeds and % quality seed recovery at Islamabad 2020 (Table 19 see in appendix). Hand-picking combined with mechanical harvesting (with desiccant) resulted in lower % of broken seeds and % seed loss compared to sole mechanical harvesting. The %broken seed and % discolored seeds were considered as combined loss to the seed production, therefore, reflected as %combined loss which was reduced from total yield to calculate %quality seed recovery. However, the %seed loss is not included in the overall yield hence not included in the combined losses %. The combined losses ranged from 18.15 to 35.67% at Islamabad during 2018, from 19.43 to 38.33% in Islamabad 2019, and from 18.68% to 36.92% across both the years (Table 17 & 18). The %quality seed recovery ranged from 64.33 to 81.85% at Islamabad 2018, from 61.67% to 80.57 in Islamabad 2019, and from 63.08% to 81.32% across both the years (Table 17&18 see in appendix). The %quality seed recovery was ranged from 82.80% in only mechanized harvesting to 96.89% in three hand-harvesting treatments at Islamabad during 2021.

Figure 13. Mungbean harvesting trial before desiccant application at NARC 2019

Figure 14. Mungbean harvesting trial after desiccant application at NARC 2019

Figure 15. Machine harvesting trial of mungbean at NARC, Islamabad Pakistan, 2019

Myanmar: The DAR Agricultural Mechanisation Department (AMD) fleet is in majority made up of Kubota DC 70 G harvesters configured for cereal harvesting. The AMD district depot held stock in the part store that included the components comprising the factory-supplied edible bean modification kits to suit Kubota DC 70 G harvesters which make up the majority of AMD's relatively extensive harvester fleet. In discussion with the Department and Depot Management, it was apparent that the subject Kubota DC 70 G harvester was scheduled to have the edible bean kit fitted during the current harvester refurbishment program, presenting a significant opportunity for improvement in mungbean harvesting.

The required modification in Kubota DC 70 G combined harvesters was done to make mungbean harvesting efficient with reduced seed losses and damage. The real-nylon 6 reel tine (iron in cereal harvester) was kept for less damage on mungbean seed. The sieve size of 7 mm was identified efficient for harvesting to get clean grain and reduce losses. The cutter bar angle was adjusted 10° from 27° to separate seed and stem effectively. The belt for cup up loader of seed was used. Three pairs of pulley were used to reduce speed from 560 rpm/min to 295 rpm/min resulted in the reduction of seed damage. The modifications done in combined harvester are documented in Burmese (Figure 16). The first harvesting trial at 2018 was conducted at Tatkone Research Farm with the collaboration of AMD with supporting of Kubota by fitting with bean kit. However, the bean kit from Kubota Co., was brought to Nay Pyi Taw office during second year (2019) and the expert team from Kubota extended services to change the necessary parts and technical guidance before harvesting (Figure 17). The modifications in combine harvester tried for mechanical harvesting experiments are listed in Table 20.

Table 20 The modifications in Bean Kit BK-70G harvester settings tried for mechanical harvesting in mungbean in Myanmar.

Particulars	Specification	Harvester setting	
Cutting	Pickup Reel Diameter × Width (mm)	900 × 1903	
	Height Adjustment	Hydraulics	
	Gathering Length (mm)	2075	
	Cutter Bar Length (mm)	1980	
	Cutting Height Range (mm)	819	
Threshing /Separating	Threshing System (mm)	Spike Tooth Axial Flow	
	Threshing Cylinder	Diameter × Length (mm)	620 × 1650
		Revolutions (rpm)	560
		Concave Area (m^2)	0.9
		Sieve Case Length × Width (mm)	1375 × 840

Figure 16. Modification done in Kubota DC 70G combined harvesters in Myanmar in Burmese language.

Figure 17. Installing bean kit on Kubota DC 70G combined harvester in Myanmar.

Seven mechanical harvesting trials were conducted at Tatkone (3 trials), and Sebin (4 trials) locations of Myanmar from 2018 to 2021 using popular mungbean varieties Yezin 11 and Yezin 14 (Table 2). There was a non-significant difference between hand harvesting (farmer's practice), modified harvester with desiccant, and modified harvester without desiccant, for seed yield at Sebin during 2018 whereas it was a non-significant difference among all the treatments for seed yield and %seed loss at Tatkone during 2018 (Table 21). The %quality seed recovery was ranged from 68.65% in treatment with modified harvester to 92.10% in hand harvesting at Tatkone 2019. There was a significant difference between the treatments: hand harvesting, modified harvester with and without desiccant, for seed yield and %seed loss at Sebin during 2019. The seed loss of around 56.82% was noted when modified harvester was used with desiccant followed by Modified harvester without desiccant (48%) compared to hand harvesting (11%) at Sebin during 2019 (Table 22). At Tatkone during 2019, hand harvesting (farmer's practice) and Modified harvester without desiccant have non-significant differences for seed yield. All the treatments had significant differences for % broken seeds, %discolored seed and %seed loss (Table 22). The highest %broken seeds recorded in modified harvester with desiccant (9.50%) followed by modified harvester without desiccant (6.43%) compared to hand harvesting (0.41%). The highest %seed loss was recorded in modified harvester with desiccant (35.02%) followed by Modified harvester without desiccant (10.47%) compared to hand harvesting (7.06%) at Tatkone during 2019 (Table 22). Contrastingly, there was a non-significant difference observed among treatments for seed yield and % seed loss at Sebin during 2020. However, a significant difference among the treatments was recorded for %seed loss at Sebin 2021 (Table 23). The highest %seed loss recorded for treatment only mechanized harvest with desiccant (22.30%) followed by 1 hand picking + mechanized harvest with desiccant (16.92%) with non-significant difference among them (Table 23). There was a non-significant difference among the treatments for seed yield at Tatkone during 2020 whereas the differences were significant for % seed loos and %broken seeds. The highest %seed loss was recorded in only mechanized harvest with desiccant (18.51%) followed by 1 hand picking + mechanized harvest with desiccant (10.62%) and 3 hand pickings (9.96%) (Table 24). The differences among the %seed losses from one location to other across years are due to the environmental conditions especially rains during the harvesting time as the trials were conducted in monsoon season.

Table 21. Effect of mechanical harvesting on seed yield, seed discoloration, broken seeds, and seed loss at Sebin and Tatkone, Myanmar during 2018.

S. No	Treatments	Sebin 2018		Tatkone 2018		
		%Seed Loss	Seed Yield (Kg/ha)	%Seed Loss	Seed Yield (Kg/ha)	SEM(±)
1	Cereal harvester (with desiccant)	23.12	192^{b}	14.70	479	45.29
2	Cereal harvester (without desiccant)	24.33	209^{b}	14.32	388	58.47
3	Hand harvesting (farmer's practice)	12.54	400^{a}	16.56	452	45.29
4	Modified harvester (with desiccant)	4.01	423^{a}	16.35	579	45.29
5	Modified harvester (without desiccant)	20.58	386^{a}	18.80	457	58.47
	CV(%)	27.73	22.33	15.98	16.66	
	SEM±	0.64	41.54	0.37	-	

%Quality seed recovery was calculated reducing the % seed breakage and %seed discoloured from the total seed yield.

Table 22. Effect of mechanical harvesting on seed yield, seed discoloration, broken seeds, and seed loss at Tatkone and Sebin, Myanmar during 2019

S. No	Treatment	Tatkone 2019						Sebin 2019	
S. No	Treatment	% Seed Loss	Seed Yield (Kg/ha)	SEM(±)	% Broken Seed	% Discolored Seed	%Quality seed recovery#	% Seed Loss	Seed Yield (Kg/ha)
1	Hand harvesting (farmer's practice)	7.06[c]	895[a]	84.8	0.41[c]	7.49[b]	92.10	11.08[b]	439[a]
2	Modified harvester (with desiccant)	35.02[a]	363[b]	103.9	9.50[a]	21.85[a]	68.65	56.82[a]	153[b]
3	Modified harvester (without desiccant)	10.47[b]	944[a]	103.9	6.43[b]	4.86[c]	88.71	48.06[a]	154[b]
	CV(%)	9.15	25.86		9.61	7.26		11.62	20.49
	SEM±	0.16			0.09	0.11		0.31	22.77

%Quality seed recovery was calculated reducing the % seed breakage and %seed discoloured from the total seed yield.

Table 23. Effect of mechanical harvesting on seed yield, seed discoloration, broken seeds, and seed loss at Sebin, Myanmar during 2020 and 2021

No	Treatments	Sebin 2020				Sebin 2021	
		%Seed Loss	Seed Yield (kg/ha)	%Broken Seeds	%Quality Seed Recovery#	%Seed Loss	Seed Yield (kg/ha)
1	1 hand picking + mechanized harvest with desiccant	7.43	1020	0.21	99.79	16.92[a]	807
2	2 hand pickings + mechanized harvest with desiccant	8.42	937	0.16	99.84	7.61[b]	1019
3	3 hand pickings	7.44	1013	0.21	99.79	8.71[b]	919
4	Only mechanized harvest with desiccant	10.55	970	0.20	99.80	22.30[a]	873
	CV(%)	14.55	14.89	18.16		15.59	10.33
	SEM±	0.21	73.35	0.04		0.33	54.00

%Quality seed recovery was calculated reducing the % seed breakage and %seed discoloured from the total seed yield.

Table 24. Effect of mechanical harvesting on seed yield, seed discoloration, broken seeds, and seed loss at Tatkone, Myanmar during 2020

No.	Treatment	%Seed Loss	Seed Yield (kg/ha)	SEM±	%Broken Seeds	%Quality Seed Recovery#
1	1 hand picking + mechanized harvest with desiccant	10.62[b]	854	101.02	12.45[a]	87.55
2	2 hand pickings + mechanized harvest with desiccant	5.20[c]	1256	101.02	12.14[a]	87.86
3	3 hand pickings	9.96[bc]	1096	101.02	6.06[b]	93.94
4	Only mechanized harvest with desiccant	18.51[a]	1092	121.41	3.18[c]	96.82
	CV(%)	18.13	10.79		5.86	
	SEM±	0.30				

%Quality seed recovery was calculated reducing the % seed breakage and %seed discolored from the total seed yield.

Figure 18. Machine harvesting field (Kubota DC 70G) of mungbean at Tatkone Research Farm

Bangladesh: One mechanical harvesting trial was conducted in Bangladesh at Ishwardi during 2019 using two popular variety MARI Mung 7 (Table 2). The results revealed that there was a significant difference among the treatments for seed yield at Ishwardi during 2019. The highest seed yield was recorded (Table 25) in hand harvesting (1267 kg/ha) followed by treatment modified JEILONG 4L-BZ 110 KYM machinery with Glyphosate (1%) (846 kg/ha) and modified 4L-BZ 110 KYM machinery without Glyphosate (751 kg/ha). The treatment of hand-harvesting (farmer practice) had a significant difference with other machine harvesting treatments for %broken seeds, %discolored seeds, and %whole seeds. The highest % seed loss was recorded in Modified Daedong with Glyphosate (1%) (21.10%) followed by Modified Daedong - without Glyphosate (15.74%) compared to hand harvesting (9.75%) (Table 25). The %broken seed and % discolored seeds were considered as combined loss to the seed production, therefore, reducing from total seed yield to get %quality seed recovery. However, the %seed loss is not included in the overall yield hence not included in the combined losses %. The combined losses ranged from 10.89% in hand harvesting to 46.18% in modified Daedong - with Glyphosate (1%). The %quality seed recovery ranged 54.14% in Modified Daedong - without Glyphosate and 89.11% in hand harvesting (Table 25). The lower seed recovery in mechanical harvesting could be due to the losses due to machine as the harvester settings used in this trials were similar to the cereal harvesting setting.

Table 25. Effect of mechanical harvesting on seed yield, seed discoloration, broken seeds, and seed loss at Ishwardi, Bangladesh during 2019.

No	Treatment	%Seed Loss	Seed Yield (kg/ha)	%Broken Seeds	%Discolo red Seeds	%Whole Seed	%Quality Seed Recovery[#]
1	Hand harvesting (farmer practice)	9.57[b]	1267[a]	5.55[c]	5.34[d]	94.33[a]	89.11
2	Modified 4L-BZ 110 KYM machinery - with Glyphosate (1%)	10.25[b]	846[b]	24.97[b]	11.69[b]	74.99[b]	63.34
3	Modified 4L-BZ 110 KYM machinery – without Glyphosate	10.68[b]	751[c]	28.95[ab]	8.56[c]	70.98[bc]	62.49
4	Modified Daedong - with Glyphosate (1%)	21.10[a]	679[d]	32.25[a]	13.93[a]	67.63[cd]	53.82
5	Modified Daedong - without Glyphosate	15.74[ab]	617[e]	34.29[a]	11.57[b]	65.64[d]	54.14
	CV (%)	13.90	3.45	6.20	4.83	1.73	

	SEM±	0.29	16.59	0.17	0.09	0.09	

%Quality seed recovery was calculated reducing the % seed breakage and %seed discoloured from the total seed yield.

Figure 19. Machine harvesting field of mungbean at BARI Ishwardi, Bangladesh

7.3 Chemical residue analysis in mungbean seed

The seed samples harvested from field trials (3 countries), 15 days after harvest were sent to globally accredited analytical lab (Eurofins Pvt Ltd, Bengaluru) in India, for chemical residue detection. Out of 130 (60-Pakistan, 30-Bangladesh & 40-Myanmar), 40 samples were used for each desiccant.

Samples analysed for respective chemical residues were compared with standard (globally accepted) permissible limit (prescribed by EU and APEDA). Of the 4 chemicals (~40 samples for each desiccant), no traces of chemicals were detected, except in only nine samples (4 from Bangladesh, 2 from Myanmar and 3 from Pakistan), relatively higher levels of Gly (0.103 to 0.573 ppm) was detected (Table 26). Possibly, the source of Glyphosate and the purity of the chemical sold in each country by various vendors might cause these discrepancies. Around 15 seed samples from a desiccation trial conducted in Bangladesh during 2021 that includes five treatments and three replications were tested for chemical residue at Eurofins Lab, India. The results indicate that the seed samples from treatments with Glyphosate 0.5% + 1% Ammonium sulfate and Glyphosate 0.3% + 1% Ammonium sulfate did not comply for glyphosate residue whereas other treatments such as urea, thiourea and ethrel comply the permissible limit of chemical residue as per EU standards.

Table 26. Residue analysis in mungbean seed: (3 countries: 130 samples)

1. **Bangladesh (Location: Ishwardi)**

Desiccant	Result	EU MRL	Remarks
Urea	Not Detected	-	-
Thiourea*	Not Listed	-	-
Ethrel	<0.01	0.05 (mg/kg)	Complies
Glyphosate	0.01-0.573 (5 samples) 2.45 (1 sample)	0.1 (mg/kg)	2 samples comply 4 samples didn't comply

2. **Bangladesh- 2021 (Location- Madaripur)**

Desiccant	Result	EU MRL	Remarks
Urea	Not Detected	-	-
Thiourea*	Not Listed	-	-
Ethrel	<0.01	0.05 (mg/kg)	Complies
Glyphosate	0.249-0.685 (6 samples) <0.01 (9 samples)	0.1 (mg/kg)	9 samples comply 6 samples didn't comply

3. **Myanmar (Location: Tetkone)**

Desiccant	Result	EU MRL	Remarks
Urea	0.28-0.70 (g/100g)	-	-
Ethrel	<0.01	0.05 (mg/kg)	Complies
Glyphosate	<0.01-0.503	0.1 (mg/kg)	10 samples comply 2 sample didn't comply

4. **Pakistan (Location 1: Bhakkar)**

Desiccant	Result	EU MRL	Remarks
Urea	Not Detected	-	-
Thiourea*	Not Listed	-	-
Ethrel	<0.01	0.05 (mg/kg)	Complies
Glyphosate	<0.01 (2 samples) 0.04-0.259 (4 samples)	0.1 (mg/kg)	3 samples didn't comply

5. **Pakistan (Location 2: Islamabad)**

Desiccant	Result	EU MRL	Remarks
Urea	Not Detected	-	-
Thiourea*	Not Listed	-	-
Ethrel	<0.01	0.05 (mg/kg)	Complies
Glyphosate	<0.01 (All)	0.1 (mg/kg)	All complies

*Note: Since thiourea was not listed in the detectable chemical, seed samples were subjected to other alternate chemicals like, Diuron, Linuron, Lufenuron and Isoproturon, as proxy for thiourea, but no traces were found. Further, we analysed all the four desiccants for their residue even in the check samples (water spray and dry control) also for confirmation.

7.4 Seed production by mechanical harvesting

Over 70 ha mungbean seed production plots were planted and harvested through combine harvesters in Pakistan (Table 27). The % broken seeds were ranged from 17 to 26% whereas the %whole seed ranged from 74 to 83%. The poor seed yield in 2020 and 2021 was due to erratic rainfall. The mechanical harvesting was demonstrated and adopted by the farmers. The mechanical harvesting of mungbean at farmer fields in Bhakkar district revealed that the % whole seed recovery ranged from 85.4% using New Holland 8055 (Chak 184TDA, Bhakkar) to 96.4% when ordinary pulses thresher (Chak 50TDA, Bhakkar) was used after cutting the crop through ripper (Table 28). The cost-benefit analysis done in Pakistan shows that the total cost of using combine harvester is 4500 PKR compared to 8500 PKR in manual harvesting (Table 29)

Table 27. Seed Production at NARC in collaboration with PARC Agro. Tech. Company

Year	Area (ha)	Variety	Production (t)	Combine harvester	Broken seed (%)	Whole seed (%)
2018	10	NM-11	6	New Holland 5040	26	74
2019	5	NM-11	3	New Holland 5040	18	82
2020	20	NM-11	5	New Holland 5040	18	82
2021	25	Nm11, NM16	7	New Holland 5040	17	83

Figure 20. Mungbean seed production blocks at NARC during 2019

Table 28. Seed quality data of mungbean recorded at Farmer's fields in Bhakkar

Combine harvester Model and location	Broken seed (%)	Whole seed (%)
New Holland 8055 (Chak 184TDA, Bhakkar)	14.6	85.4
New Holland 8060 (Chak 46TDA, Bhakkar)	6.7	93.3
Someca M-132 (Chak 50TDA, Bhakkar)	9.8	90.2
Ordinary pulses thresher (Chak 50TDA, Bhakkar)	3.6	96.4

In Pakistan, around 80 demonstration trials with 0.4 ha each were conducted during 2018-2021. Of these, 35 demonstration trials were conducted at Thal, District Bhakkar, one of the traditional mungbean growing areas under irrigated conditions, 35 at Potowar, District Chakwal, one of the potential areas for mungbean under rainfed cultivation, and 10 in Southern Punjab under Irrigated cotton-wheat cropping system (Table 30).

Over 450 farmers, researchers, extension workers, NGO-NRSP, harvesting service providers, and seed companies were demonstrated/trained for mechanical harvesting through field days, training programs, and awareness seminars. The details of field days, training programs, and awareness seminars conducted in Pakistan during 2018-21 are listed in Table 31 and Figure 21. The major interventions demonstrated were the benefits of improved quality seed of new varieties, improved production technology (Rhizobium Inoculum, fungicide seed treatment, IPM) and mechanized harvesting of mungbean

Figure 21. Mungbean Demonstration plots in Chakwal and Bhakkar districts

Table 29. Comparison of mechanical and manual harvesting methods at farmers' field during 2019

Method	Cost (in PKR)				Additional Income from Selling the Straw (PKR)	Net Cost (PKR)	Benefit of combine over manual harvesting
	Harvesting	Drying	Threshing	Total			
Comparison of cost							
Manual	9000		2500	11500	3000	8500	
Combine harvester	3000	1500		4500		4500	4000 PKR
Comparison of time (time in Hours required for different operations/0.4 ha area)							
Manual	10	48	2	60			
Combine harvester	1	48		49			11 hours

During 2019-20 many farmers adopted mechanized mungbean harvesting in the Bhakkar district. Farmers' interest in mechanized harvesting is helping in establishing local harvesting hubs through the involvement of service providers. Our project team also recorded seed quality data on different farmers' fields where different harvesters were used for harvesting (Table 30).

Table 30 Adoption and uptake of improved technologies of Integrated Crop Management and Mechanized Harvesting through demonstration plots 2018-2021

S. No.	Regions	**No. Demonstration plots (1 acre each)**				
		2018	**2019**	**2020**	**2021**	**Total**
1	Thal (District Bhakkar) Traditional mung bean growing area under irrigated conditions	5	10	10	10	35
2	Potowar (District Chakwal) potential area for mung bean rainfed	5	10	10	10	35
3	Southern Punjab (Irrigated Cotton-Wheat cropping system)	-	-	-	10	10
Total		**10**	**20**	**20**	**30**	**80**

Table 31 Field days/ awareness seminars conducted for the improved seed production and mechanized harvesting

Sr. No.	**Date**	**Venue/Location**	**Title**	**No. of Participants**	**Participants**
1	16-08-2018	Village Chak No. 53/TDA, Distt. Bhakkar.	Field Day: Improved mung bean production technology in Irrigated Areas of Bhakkar	80	Farmers, Researchers, Extension workers, NGO-NRSP, Service providers, seed companies
2	23-10-2019	Village Chak. 50 TDA, Distt. Bhakkar	Field Day: Demonstration of Mechanized harvesting in mung bean	60	
3	08-08-2020	Village Dagar Rahtas, Distt. Bhakkar	Field Day: Demonstration of Mechanized harvesting in mung bean	92	
4	14-10-2020	Village Chakora, Distt. Chakwal	Field Day: Demonstration of Mechanized harvesting in mung bean in Pothwar region	110	
5	03-06-2021	Village Jatli, Dist. Rawalpindi	Awareness Seminar: Improved Production Technology and mechanized harvesting in mung bean	30	
6	04-06-2021	Village Kot Sarang, Distt. Chakwal	Awareness Seminar: Improved Production Technology and mechanized harvesting in mung bean	50	
7	29-12-2021	NARC, Islamabad	Training course on Harvest and Post-Harvest Management of Pulses.	30	
Total				**452**	

7.5 How Will Mechanizing Mungbean Harvesting Affect Women Hired Laborers in Myanmar and Bangladesh?

7.5.1 Quantitative Data Findings

In the quantitative survey, we found that mungbean farmers planted on average 0.18 ha of mungbean per year in Bangladesh and 3.42 ha in Myanmar. Each hectare planted with mungbean provided on average 35 labor-days of employment across all tasks for hired women in Bangladesh and 31 in Myanmar. Hired men obtained about 10 labor-days across all mungbean tasks in Bangladesh and about 9 in Myanmar. Taken together, hired laborers provided about half of all labor required in Bangladesh, and about 81% in Myanmar where the planted areas are larger. Particularly for women, most of their work and thus wages were in mungbean harvesting. In Bangladesh, farmers paid on average a total of 115 USD per hectare to women hired for harvesting, whilst farmers in Myanmar paid women about 110 USD per hectare (Currencies are converted using the annual average of the official exchange rate to USD of 2018 for Myanmar (1429.808 MMK/USD) and of 2019 for Bangladesh (84.454 BDT/USD).) As fewer men were hired for the harvest, farmers paid on average 9 USD per hectare to men in Bangladesh and 16 USD per hectare to men in Myanmar. In both countries, wages for all activities on the fields before the harvest total about 40 USD per hectare for men and women combined. This work is mostly done by men workers in Bangladesh but equally shared between men and women in Myanmar. Post-harvest activities on the farm provide about 4 USD per hectare to women and men hired workers in Bangladesh and 9 USD per hectare in Myanmar. Combining these results with national statistics of mungbean production, our data suggest that in Bangladesh the mungbean harvest provides ca. 4.75 million USD of annual income to rural women laborers and 0.37 million USD to men laborers. In Myanmar it provides 134.75 million USD to hired women and 20.33 million USD to hired men (Farnworth et al. 2020)

7.5.2 Qualitative Data Findings

Research Question 1. "How Is Mechanizing Mungbean Harvesting Likely to Impact upon the Income of Women Workers?"

We assessed the number of days women and men work in mungbean harvesting, and the wages received. Whilst the quantitative survey shows the importance of wages at the population level, the qualitative data shows the relative importance of income from mungbean harvesting compared to wages in other forms of fieldwork. We further considered that it was important to break down the actual tasks women and men perform in mungbean harvesting so as to avoid assumptions about their work. For instance, women's work in land preparation and pesticide spraying is often overlooked. Given the small sample of respondents, we do not present how many respondents in our sample earned a specific income. Rather, we provide the full range of data provided by the respondents in relation to days worked and income. In our research sites in both countries, hired workers are recruited from within the community directly by farmers rather than through agents. Hired laborers are paid only in cash. The exception in all sites is when a hired laborer is indebted to the farmer due to borrowing money; then they must work on the farmer's fields to repay the loan. **In Myanmar**, in **Village 1**, farmers hire laborers as individuals but in **Village 2**, a farmer asks one hired laborer to organize a group of men, or women, depending on the task. Often, when women obtain work, their husband or other family members must take on their household and childcare tasks. In Bangladesh, women prefer to work with the same group of women year after year. Some men form groups, and others work as individuals. Women we met in Bangladesh needed their husband's permission to work in mungbean harvesting or any other task. They also performed the majority of household and care work though many men contributed in minor ways to childcare, cooking etc. It should be noted that in Myanmar in our two sites, the women to men labor force in mungbean harvesting averages 80% women to 20% men (or at the most 70%:30%). In the Bangladesh sites, very few men (a handful) work on harvesting mungbean. The figures in the table thus do not mean that all men work on mungbean harvesting, but rather show the number of days worked by men on average should they work in harvesting mungbean. In both sites, women and men work from 7 am to noon with a one- to two-hour lunch break. They then resume work from 2 pm to 5 pm or longer (women reported working 8 to 9 h a day on mungbean harvesting). Women's daily wage in agriculture, regardless of crop or task, is 2.80 USD per day. Men receive 3.50 USD per day. For certain tasks, such as spraying, men earn up to 4.20 USD/day. When asked what they thought about the gender gap in wages, some women said that men work harder than women, but another said*, "According to tradition, men get more wages than women, but there's no reason for it and I cannot agree with it".*

In Village 1 women workers are hired for hand weeding and carrying water for foliar and pesticide application, which happens twice during the mungbean growing season. Spraying is normally done by men though a few women spray. Fieldwork provides women with about 10 to 15 days work a year. During manual harvesting in January through to February, women work 8 to 10 h per day for up to 30 days. Mungbean pods are not handpicked. Rather, the whole mungbean plant is uprooted, sundried and then mechanically threshed. Almost all women hired workers glean mungbean from the fields for around 15 days after the harvest. This involves collecting the fallen bean pods, threshing using a stick, sun drying, sieving for contaminants such as small stones and chaff, and selling directly to small buyers in the village. Some farmers allow hired workers to keep all the mungbean they glean whereas others request half of the product. If mungbean is manually harvested, each person can glean around 1.25 baskets (one basket is 32.7 kg–23.78 USD) over five days. This results in an income of 89.17 USD from 3.75 baskets for 15 days. Gleaning after manual harvesting provides high-quality mungbean. However, mechanized harvesting is proving less favorable to gleaning. The quality is lower because mechanical harvesting can crush beans and pods, and also some beans are unripe. Each person can glean for around five days, and are only able to collect around one basket. This means women receive less money. In total, women in Village 1 work for 55 to 60 days per year on mungbean (30 days in manual harvesting). This suggests that women earn an average of 83.93 USD for manual harvesting, and the same again for other tasks. The income range is 83.93 USD to maximum 215.06 USD. The recent mechanization of mungbean harvesting has, however, removed a significant source of income for women. One woman explained how she is coping, *"I have to pick wild vegetables and sell them, and I sell fish. Just yesterday I was diving in the irrigation canal for edible snails to sell".* It should be noted that though men can obtain work harvesting mungbeans in nearby villages, this option is not open to married women due to their mobility constraints. As noted above they are expected to take care of children, other family members, livestock and to maintain the household in general.

Hired men in Village 1 are involved throughout the production cycle in mungbean harvesting, including land preparation using tractor and power tillers, cleaning the field (for men this means removing small bushes), broadcasting seed, foliar fertilizer application, herbicide spraying (men bring water themselves), pesticide spraying, inter-cultivation (weeding, hoeing), manual harvesting (though to a lesser extent than women) and threshing. Prior to mechanical threshing, men worked for 20 days threshing mung. Today, they work for just five days. In total, men work between 34 to 45 days on mungbean, with some men obtaining an additional twenty days per year if they follow the harvest elsewhere. Men can earn approximately 101.41 to 139.88 USD in mungbean harvesting (plus an additional 69.94 USD if they follow the harvest to local villages).

In Village 2 in the Central Dry Zone, women's work in mungbean harvesting ranges from cleaning the fields (which for women means removing brash and crop residues from ploughed fields) and applying basal fertilizer and seeds into rows prepared by men, to harvesting and post-harvest operations. Harvesting involves handpicking mungbean and is conducted two to three times. During the third harvest, some farmers hire workers to uproot harvested mungbean plants (i.e., residue) for cattle fodder (a very few hired respondents both have cattle and use residue as fodder). There is no gleaning. Women are engaged for between 44–68 days per mungbean season and earn 2.80 USD/day (123.09–190.24 USD). Of this, 10 to 15 days are in harvesting (27.98–41.96 USD). Men have around 30 to 40 days work per mungbean season and receive 3.50 USD/day (104.91–139.88 USD).

In Villages 3 and 4 in Bangladesh, women rarely engage in field activities associated with mungbeans. However, harvesting mungbean is considered a woman's task, though a very few men—the poorest—also pick mungbean. Working hours are the same for both genders. The day starts at 7 am with breakfast at 9 am for 20 min. Lunch is from 2–3 pm. Workers finish between 5 pm and 6 pm. Men and women workers are paid the same piece rate per kilo instead of a fixed daily wage.

In Village 3, women pick pods for 30 days. They also have another 10 to 15 days in post-harvest operations. The piece rate varies by harvest. For the first picking, women are paid 0.12 USD/kg. For the second picking, they receive 0.14 USD/kg and for the third picking, 0.18 USD/kg. There is a fourth picking where hired workers share 50% of the crop with the smallholder. On average, women pick 15 kg of mungbean per day. This gives nominal figures across the season of 1.78 USD/day; 2.13 USD/day and 2.66 USD/day. Post-harvest operations include grading mungbean for five days, winnowing for three days, drying for three days and threshing for four days (this is about 15 days but the days required to vary between 10 to 15 days). They are paid about 2.37 USD/day. It is rare for hired workers to glean though farmers invite widows and elderly people to do so. In total women obtain 30 days harvesting mungbean, and about 10 to 15 days on post-harvest operations (40 –45 days a year), thus earning between 71.04 and 106.57 USD in total.

Men in Village 3 are engaged in all field tasks for mungbean. This includes land preparation, weeding and spraying. For most tasks, men are paid an average daily wage of 2.96 USD for a half day (7 am to 1 pm). For specific tasks men are paid piece rates (0.59 USD for 0.13 ha of land), for example for spraying pesticides. In total, men work for around 40–45 days in mungbean (excluding harvesting and post-harvest processing), earning between 118.41 to 133.21 USD. As mentioned, only the poorest men harvest mungbean. Whereas one wealthy farmer contemptuously described men harvesting mungbean as 'weak' and claimed it is not a man's job, a landless laborer described how he works every day as a hired laborer—mostly in sugar cane—from 6 am to 1 pm (seven hours). Meanwhile, his wife tends their two dairy cows and takes care of their child and household. They eat together and rest and then—in the mungbean season—both harvest mungbean together—as hired labor—from 3 pm to 7 pm or until darkness falls. This equates to at least an 11-h day for the male hired laborer, and the woman works a similarly long day. It is hard to consider such a man 'weak' and the remark by the wealthy farmer suggests a gap in understanding of the reality of people's lives between community members.

In Village 4, women work for an average of 30 days on manual harvesting. A few women glean mungbean for home consumption (2 to 3 kg of mungbean from 0.4 ha). Women thus obtain between 40 to 45 days a year of work on mungbean on harvest and post-harvest operations and they earn between 125.51 and 137.35 USD. As in Village 3, men work across a range of tasks during the growing season. They obtain 45 to 55 days of work on mungbeans. The average male wage is 4.74 to 5.92 USD per day. Across the mungbean season men earn 239.78 to 293.06 USD. Men laborers also collect residues for their livestock, for free, and give them to their wives to feed livestock (nominal market value of residue 5.92 to 8.23 USD from 0.13 ha). Taken together, the findings show that for women in all study sites mungbean is an important source of income. Women in Village 1 in Myanmar work for around two months on mungbean, one in field operations and one on harvesting alone, and earn between 83.93 USD to 215.06 USD in total. In Village 2, women work between 1.5 to just over 2 months on this crop with about 0.5 months in harvesting (123.09–190.24 USD). In Bangladesh, women earn money from harvesting and postharvest operations. In Village 3, this accounts for around 1.5 month's work (71.04–106.57 USD) and in Village 4 women likewise work 1.5 months and earn 125.51 USD to 137.35 USD. Mungbean harvesting is one of the only sources of income for women in Villages 1, 3 and 4 and provides women with a significant opportunity to contribute to the household budget.

Research Question 2: Are Women Workers Likely to Be Able to Innovate into Alternative Sources of Income?

The data above suggest that women, and men to a lesser extent, will face a significant loss of income if mungbean harvesting is mechanized. This will also reduce income from post-harvest processing and gleaning. We therefore investigate whether women and men are likely to innovate into alternative livelihood activities. To do this, we discussed gender norms across the research tools and how they relate to the ability of women, and men, to innovate. In FGD 4, we asked: What characteristics help women, or men, to succeed in a new enterprise? Which factors promote, or hamper women and men who want to innovate?

In Myanmar, respondents in Village 1 argued that women and men innovators share some characteristics. They need to be willing to work hard, be creative, have good management skills and have access to sufficient funds. The characteristics ascribed specifically to women innovators, however, are deeply influenced by assumptions around their gender roles. As noted above, almost all our women respondents were married with families and are considered primary carers. Therefore, it was argued that women must be good at allocating time between their business, care and household activities. Critically, women need the support of their spouse and wider family to innovate. Men also need the support and trust of their family, but this is less of a deal-breaker than for women. Men are more likely to be innovators because men are already associated with decision-making over large sums of money, whereas women—though they hold the household budget—are able to make independent decisions only over small sums. Women had few ideas when asked how they could respond to mechanization of mungbean harvesting. They suggested opening pharmacies or grocery shops, buying land and livestock. However, in general they argued that the village is simply too small to accommodate many businesses, and well-educated women—"we have so many graduates"—also find it almost impossible to find work. One woman (Village 1) explained, "Some young women can out-migrate, but we all have children, and have to care for them. We don't have any networks to help us migrate, and we cannot take our families if we don't know where we can sleep. We are scared to do that".

In Village 2, respondents claimed that women are usually less innovative than men. However, this is slowly changing because young, educated women want to do things differently. Furthermore, training courses in leadership and communication skills are encouraging women to participate in different activities. Men who are good leaders and communicators, and who are knowledgeable, always seek to innovate. Respondents argued that women and men need technical support, training, sufficient money and motivation to do new things. However, even if women have these things, norms which frame men rather than women as innovators continue to pose a significant barrier to women's ability to do new things. For example, respondents argued that women have the capacity to use machinery since modern machinery is considered easy to handle. However, most women said they are afraid of machines and do not trust themselves with them. They feel that handling, managing and repairing machinery is a man's job.

In Bangladesh, respondents in Village 3 thought that young, intelligent, educated women who are eager and courageous may be able to change their situation. A few women have innovated in terms of technology, for example by using electric fans rather than bamboo sticks to winnow some crops. However, women respondents working in mungbean harvesting—who, as in Myanmar, are mostly married with children—said that innovation was difficult due to a lack of family support, insufficient money, lack of local government/NGO support and criticism from the community. Men respondents commented that, *"It's really tough to be a woman innovator. In our society a woman cannot do anything alone, she needs permission from the family to go outside or to do anything".*

Gender norms expressed by some men respondents in Bangladesh suggest that women should prioritize their household and care work and focus on raising livestock. Women who leave their homes can face abuse from community members. However, practice can be different. An important innovation in Village 3 is that more women have started working in the fields over the past five years or so. This is largely a consequence of the rapid increase in agricultural productivity in the past decade, reported above. More labor is required, yet men's labor is insufficient. This is partly because men are mobile and can pursue more lucrative opportunities elsewhere, but also because some wealthier men refuse to work in agriculture. Beyond this, increased education and social awareness are seen as contributing causes to women's ability to earn money outside the home. A community profile respondent (man, Village 3) indicated that in the past "society did not accept women working in the fields, nowadays, it's accepted as a job. She's earning for her family". A hired woman in the same community said, '*Society honors women who work as hired agricultural labor. They respect us. They know we are working for the family. If you can give a contribution it raises your prestige. People look at you in a different way".* This contributes to the community level empowerment of poor women. "Even poorer women are now able to go to the Union Parishad and raise their issues and expect to be listened to. Her issues are taken seriously" (Community profile respondent, man). When asked what they would do if mungbean harvesting was mechanized, women rapidly listed some ideas, such as embroidery and making quilts. However, as in Myanmar, women would need support in developing such cottage industries, and in particular in selecting competitive businesses.

In Villages 3 and 4, social norms permit men to freely pursue their interests. Male respondents in Village 3 commented that "Men have enormous power and liberty to do what they want. We don't need to think about social limitations. So, we have the maximum possibility to innovate". Men are under no obligation to consult with their wives. Even so, several men said they "discuss everything with my wife". Although men, as in Myanmar, tend to make key decisions around large assets, poor men do not have such assets. A lack of capital, land and lack of local political support often hinder poor men from doing things differently. One man said, "*Our life is painful. You cannot understand it. It is difficult to earn money by selling your labor in the fields. Poor people like us live hand to mouth".*

Research Question 3. How might this Change in Income Affect the Economic and Personal Empowerment of Women Workers?

In the introduction, we said we were interested in whether the loss of income from mechanizing mungbean harvesting could hamper the ability of women to make a meaningful life. Our data shows that for women, their ability to contribute to their family's needs, develop a sense of self-esteem and develop a sense of renewing cultural identity are all important to them. In both countries women's visible participation in fieldwork and in providing income to their families earns them respect from their families and from the wider community. In Myanmar, the normative assumption is that women need to engage in paid work. Their earnings are important to meet household needs. Today, no household can depend only on a man's income. Women's economic contributions are noticed and valued in the household and in the community. Whilst a few women respondents in Village 1 said that mungbean was not key to their family's livelihoods, other women said it was very important. "It is my main source of income", and "Income from mungbean is higher than selling fish and vegetables". The data shows that income from mungbean forms 50–100% of a woman's earnings in this community. The money is spent on all household needs including food, clothes, school fees, livestock inputs, social occasions, health and more.

Whereas in the past in Bangladesh women working in the fields were considered to be of exceptionally low status, all the hired women respondents we met were proud of their work in harvesting mungbean. Their financial contribution is valued by their husbands and recognized as important by many others in the community. Women would certainly swop fieldwork for easier work should it exist—but the income they currently earn from fieldwork is vital to their sense of self-esteem. It is important to their household's functioning, too, with women and men agreeing that women's income is critical to the education of their children. One man (Village 3) confirmed that his wife's income from mungbean covered one month of their outgoings and added, "We cannot run the family without my wife's income". Women use their income to keep their children in school and into college. Children recognize their mother's efforts and "see it as important". One woman (Village 3) commented *"My children are my dream and my life. I invest my income and my life in both of them. I pray they won't be like me. They'll create a position for themselves in society".* Turning to the renewal of cultural identities, in Myanmar it became clear that the importance to respondents of being able to engage in various Buddhist ceremonies and community works cannot be underestimated. They wanted to participate in donation ceremonies (which includes providing food to the local monastery) and more generally through 'good deeds,' which includes providing free labor to community works. These issues were raised by respondents because such deeds help towards effective reincarnation, as well as contribute to village development and thus build good social capital. However, hired workers generally do not have enough time for such works, though they do contribute annually to road repair. Hired women (Village 1) reported that "We try hard to contribute to the wellbeing of the community, but we have little time and leisure to relax. We only have an average of 15 days income per month and the other days we are always busy in mind trying to find work and money". Another added that "We can't give money or food, but we can donate our time. We contribute physical labor. Every year the roads have to be rebuilt after the floods in September or October so we help for free".

In Bangladesh, respondents face similar issues in relation to their ability to contribute effectively to community needs and causes. Since men have much higher mobility, this was particularly an issue for male hired laborers. As in Myanmar, men contribute labor rather than money to local causes. This may include road maintenance, water switch gate operating and helping to build mosques.

7.6 When Machines Take the Beans: Ex-Ante Socioeconomic Impact Evaluation of Mechanized Harvesting of Mungbean in Bangladesh and Myanmar

7.6.1 Results of surveys

Our data show that in our sample mungbean farming households in Bangladesh and Myanmar are on average home to about four household members. One percent of surveyed farms in Bangladesh and 9% of farms in Myanmar are headed by a woman and the share of households where a woman is responsible for mungbean production is only 1% higher in each country. Farmer respondents in Bangladesh own on average 0.65 ha of land and plant mungbean in a single season on 0.18 ha. Farmer respondents in Myanmar own an average 5.43 ha, grow mungbean on average in 1.1 seasons and plant a total of 3.14 ha. This equates to around 17 times more land devoted to mungbean per household than in Bangladesh. In both countries, the crop stays about 80 days in the field and yields just above 0.9 t/ha. This equates to a financial value of about 650 USD/ha. Farmers in Bangladesh keep a larger share to consume, share and save as seed (ca. 90 kg/ha from the total). Farmers in Myanmar kept a smaller quantity (ca. 40 kg/ha from the total), which corresponds approximately to the seed rate required to replant the area.

Production costs per hectare were significantly higher in Myanmar than in Bangladesh (432 compared to 364 USD/ha), though neither the difference in input cost nor in labor cost is significant on its own. Labor costs contribute more than 40% of the total production cost in both countries. About two thirds of this cost are wages to women hired for harvesting (115 USD/ha in Bangladesh, 114 USD/ha in Myanmar). Men are much less commonly employed in the harvest, with expenditures on men workers being 9 USD/ha in Bangladesh and 16 USD/ha in Myanmar. The average wages per 8-h labor-day are similar for men and women. Overall, though, wage costs are considerably higher in Myanmar (4.36 USD per hired woman and 4.51 USD per hired man) than in Bangladesh (3.64 USD per hired woman and 3.65 USD per hired man). Profits from mungbean production average around 215 USD/ha in Myanmar and 295 USD/ha in Bangladesh. Due to the large variation within both countries, this difference is not statistically significant. However, as the area planted to mungbean per farm is about 17 times smaller in Bangladesh than in Myanmar, the average mungbean producing households in Bangladesh earned on average 58 USD from mungbean, compared to 1019 USD in Myanmar. Mechanized land preparation was adopted by all mungbean farmers in Bangladesh and 85% in Myanmar. While no farmer in Bangladesh used machinery to harvest the crop, 5% of the farmers in Myanmar had started using a modified combine harvester in the mungbean harvest.

In Bangladesh, the production of 1 ha of mungbean took on average about 82 standardized 8-h labor-days from family members, hired laborers and to a smaller degree children and workers without monetary pay. In Myanmar, production of 1 ha required an average of 52 labor-days. In Bangladesh, hired women provided about 34 labor days per hectare (75% of all labor required for the harvest). In Myanmar, hired women provided about 27 labor days per hectare (81%) to the harvest. Hired men provided three and four days per hectare, respectively. Smallholder family members of both genders provided four labor days per hectare to the harvest in Bangladesh and one day per hectare in Myanmar. The differences in the average area planted by each farm mean that differences in the per-hectare statistics do not reflect the differences in the workload per household. Regardless of the total land area planted to mungbean, family men and women spend less than one-day harvesting mungbean in Bangladesh and just over three days in Myanmar. It is not clear whether this work involved actually picking alongside hired laborers or supervising this work.

7.6.2 Drivers of Mechanization in the Mungbean Harvest

Partial Budget Analysis of Mechanized Mungbean Harvesting

First, our ex-ante partial budget analysis relies on the experience of labor substitution in the rice harvest. Our data show that, while 93% of mungbean farmers in Bangladesh grew rice, none of them used a (mini-)combine in the rice harvest. In Myanmar, 73% of mungbean farmers had grown rice over the previous year, mostly planted during the monsoon season. Of these farmers, 64% used a combine to harvest the monsoon rice, paying an average 81 USD per hectare for this service. Comparing the labor requirements with the combine harvester with farmer estimates of labor demands prior to mechanization shows a reduction in the employment of hired women by 98% and that of hired men by 83%. Farm household labor reduced by 51% for women and 70% for men. We assume that the same reductions would apply for mechanized harvests of mungbean, excluding previous hand pickings. Second, the regression results suggest that a reduction in the number of harvests is associated with a reduction in the required labor, irrespective of mechanization. The labor required for production increases significantly with harvesting frequency. Compared to a single harvest, adding a second harvest is associated with a 41% increase in labor hours. Switching from one to three harvests is associated with a 113% increase and switching from one to four harvests with a 160% increase. Third, we assume that reductions in harvest frequency due to mechanization would significantly reduce crop yield. Our regressions show that in the current manual harvesting system a shift from one to two hand-harvests is associated with an 18% yield increase. A move to three harvests is associated with a 38% yield increase. Furthermore, in the current system of hand-harvesting, a reduction in the frequency of harvests to two harvests is associated with a significantly higher share of the yield being produced in the second harvest. This implies higher seed losses if the second harvest is mechanized.

Based on the model assumptions and the associations found in our data, Table 5 shows the potential effect of the three different mechanization scenarios. Due to the fixed costs of machine rental and desiccant application, the substitution of labor does not result in a strong reduction of production cost. Under full mechanization, the total production cost drops by 10–11% and with one previous hand picking they remain at the current level. A combination of mechanization with two hand pickings results in an increase in production costs. If switching to full mechanization, then yield losses would be 40% in Bangladesh and 26% in Myanmar. Full mechanization would therefore cause a reduction of average profits by 77% in Bangladesh and 59% in Myanmar. However, a harvesting regime that allows for up to two hand pickings would result in reductions by 20% in Bangladesh and 31% in Myanmar.

Due to variation between farmers, we estimate that 9% of farmers in Bangladesh and 11% of farmers in Myanmar would currently be able to increase their profits from mungbean by adopting full mechanization of their harvest. These numbers depend strongly on local wage rates. Assuming a higher labor cost while keeping all other variables stable shows that a rise in wage rates could quickly increase the share of farmers for which mechanization is profitable. If the cost of labor was to be 100% over current rates, 31% of farmers in Bangladesh and 43% of farmers in Myanmar would find mechanization profitable. At a 300% increase (the approximate increase after 30 years with 5% annual wage growth), 55% of farmers in Bangladesh and 80% of farmers in Myanmar would increase profits with mechanization. At all variations of the labor cost, full mechanization is profitable for a larger share of farmers in Myanmar than combinations with hand picking. In Bangladesh, the combination with two hand pickings is profitable for the largest proportion of farmers.

Other Economic Motivations for the Adoption of Mechanized Harvesting

Our partial budget analysis suggests that mechanized mungbean harvesting is currently only profitable for a small share of farmers. However, this analysis only captures effects on the average income. The qualitative data show that the most important reasons farmers in Myanmar and Bangladesh gave for wanting to mechanize mungbean harvesting were ensuring timeliness through avoiding the risk of rainy weather and saving labor costs. In Village 1 in Myanmar, a few mungbean fields were harvested mechanically in 2018. During the same period, catastrophic floods were experienced which ruined the mungbean harvest for most other farmers.

In 2019, rain appeared to threaten the harvest again, leading to strong demand for combine harvesters as farmers panicked. As a consequence, many mungbean fields on flat land with large fields suitable for machinery (about two-thirds of village lands) were harvested mechanically. One-woman farmer with 3.24 ha of mungbean explained her reasoning, “The cost difference between combine and manual labor for harvesting is 15,000 to 25,000 kyat per acre. But the cost is not the only issue. Timeliness is improved as combine harvesting only takes one day. Rain can ruin the entire crop, and climate change is making things more uncertain” (Village 1, smallholder woman, Myanmar).

In Bangladesh, no farmers had experienced mechanical harvesting of mungbean and could not envisage it due to their experience of hand-harvesting over several weeks. However, they generally agreed that, were the machinery to work, “We want it, it is urgent. We want it because harvesting will be less laborious and less costly. Also, it will save our valuable time. During bad weather, it will save mungbean from damage in the field” (Village 3, smallholder man, Bangladesh). Revealingly, this logic is almost precisely the same as that expressed by the woman farmer in Myanmar.

Although most farmers in Village 1 in Myanmar hired combines to harvest their mungbean in 2019, they were disappointed with the product. This is because combine harvesters had been adapted locally with little knowledge of precisely which adaptions needed to be made. Losses were high and the grain quality was poor, leading to low sales prices. Men reported, *"We experienced disadvantages using machinery and just used it to avoid poor weather conditions. If the weather is good, we just want to use manual labor. Otherwise, if all the current disadvantages are overcome through a new machine we want to use machinery for all operations"* (Village 1, smallholder man, Myanmar).

Non-Economic Motivations for the Adoption of Mechanized Harvesting

Although the quantitative survey shows that smallholder women and men do not devote much time to harvesting mungbean, this finding might not fully reflect the relative significance of the task in the agricultural year according to other criteria, for instance labor intensity and difficulty. In Bangladesh, men and women farmers equally (89%) supported the statement that mungbean harvesting is amongst the most arduous types of work on the farm. In Myanmar, just over half of women and men farmers considered mungbean harvesting to be arduous while 36% of women and 38% of men agreed with the statement that it takes little effort. Agreement with statements may depend on whether the respondent themselves engage in harvesting or supervise others in this task. In both countries, respondents agreed that hand-harvesting demands a lot of women's time (79% of men and women in Myanmar and 85% of men and 87% of women in Bangladesh) as well as men's time (66% among men in Myanmar and 79% among men in Bangladesh).

Perceptions about the benefits of time-saving benefits of mechanization are supported by respondent agreement with statements on the benefits of the already mechanized rice harvest in Myanmar. Just under 90% of men and women farmers supported statements that the introduction of combine harvesters saves men and women a lot of time. The statement that the mechanization is good for the entire family was supported by 69% of women and 73% of men. Nevertheless, about one third of men and women preferred hand-harvesting in rice. The qualitative data accord with the quantitative data in showing that smallholder women in both countries highlight time savings. *"Mechanization will save us time and fieldwork will be easy. It will reduce the time spent on harvesting"* (Village 3, smallholder woman, Bangladesh). In Village 4, almost no women were hired for mungbean harvesting meaning that the entire workload fell on smallholder women themselves.

Smallholder women highlighted burdens associated with hired laborers which mechanization would eliminate. For example, women in Myanmar prepared food for hired laborers (this is common practice in some parts of Bangladesh but not in our two study communities). While the quantitative survey of this study tried to capture it, the economic costs in terms of food bought or taken from the farm is rarely calculated in cost-benefit analyses, nor are the time costs to women. One-woman smallholder in Myanmar explained that prior to mechanized harvesting of mungbean, *"Our temporary hired workers came from Bago West. We regularly employed 30 to 50 laborers for the mungbean harvest (across 18 acres). We provided them a simple temporary place made of bamboo to sleep. It is hard to manage so many people. I have to get up at 4 am to cook rice—and pay someone to help me—in a huge pot. Then the same work for lunch and supper. We give them fish each day and meat once a week (chicken or pork). We add a few vegetables from our home garden"* (Village 1, woman smallholder, Myanmar).

It is not surprising that women smallholders highlighted time savings because they, rather than men, work in the fields on harvesting mungbean and providing for hired workers. In Myanmar, though, men smallholders also commented on time savings, saying *"We will get more time to spend with our family", and "We can do more social and community works"* (Village 1, smallholder man, Myanmar). These comments highlight an important aspect of many discussions held with respondents in Myanmar, namely the ability of individuals to contribute to community well-being, including through maintaining Buddhist temples, repairing roads and community cooking at events (which is a male task). Such deeds help to accumulate merit (important in Buddhist religion) as well as contribute to village development and social capital.

Reduction of Labor Incomes in Mechanized Harvesting

Production cost reductions attributable to mechanization lead to reduced demand for hired labor. Combining national agricultural statistics on the planted mungbean area with our data on the average rate of employment per hectare of mungbean shows that the mungbean harvest creates about 34.06 million days of employment for hired women in Myanmar and 1.39 million days employment for hired women in Bangladesh. This corresponds to wages of 141.91 million USD in Myanmar and 4.75 million USD in Bangladesh. Assuming the production area remains stable, full mechanization of the mungbean harvest implies the almost complete disappearance of this source of employment for hired women. For hired men, just 11–14% of employment would remain. If we allow for two hand pickings prior to mechanizing the final harvest, the reductions in labor requirements are smaller, at 34% for women and 28% for men. Therefore, compared to full mechanization, the average results suggest that combining mechanization with two hand pickings would result in a smaller reduction of incomes for farmers and workers alike. As farm profits derived from mungbean are not expected to increase in our model, farmers are unlikely to increase the land area devoted to mungbean production. This could otherwise have compensated for a part of the employment loss.

The views of the male and female farm household members in the quantitative survey support the finding that the mechanization of the mungbean harvest would lead to the removal of women from harvesting, with detrimental effects for hired laborers. In Bangladesh, 70% of men and women agreed that the problem about mechanization is that it reduces work and income for landless people. In Myanmar, 50% of women and 59% of men agreed. The statement that mechanization would exclude women from employment in hand-harvesting was supported by 63% of men in Bangladesh and 65% of men in Myanmar. Among women, it was supported by 60% and 54%, respectively. Only 34% of women in Bangladesh and 21% of women in Myanmar agreed with the statement that women can operate farm machinery equally well as men. The support was 2% and 3% lower among men, respectively. In Myanmar, where mechanization of the rice harvest is common, similar judgements were made. Half of men and women supported a statement that mechanization is bad for the poor and landless; 54% of women and 59% of men agreed that the role of women in the rice harvest was reduced with the adoption of combine harvesters.

Significance of Employment in the Mungbean Harvest for Hired Laborers

Women in both countries dominate harvesting—in Myanmar, the ratio of hired women to men in Villages 1 and 2 is 4:1. In Bangladesh, the employment of men is negligible in Villages 3 and 4. A closer look at which women work in mungbean shows that married women with children are the most likely to do so. This is because they are the least mobile and have the fewest alternative income-generating options. Gender norms in both countries mean that married women are expected to take care of children, other family members and livestock and maintain the household in general, leaving little time for paid work. Conversely, men hired laborers are more likely to find local work, and they are usually able to travel to other destinations to find work. Some women in Myanmar pointed out that gender norms keep the entire household poor and lock them into poverty because men are not necessarily able to adequately provide for the whole family on their own. Poor men experience low bargaining power and typically have to take on arduous low paid work. Women considered that this lack of gender norm flexibility means children are taken out of school, and necessary repairs to the home are not made. More broadly, women as well as men in Myanmar universally agreed that women's income is important to support the household. The issue is rather the degree of compromise which can be made between this objective and obeying gender norms.

Women in Village 1 in Myanmar earn 50–100% of their annual agricultural income from mungbean. Of this, 20–28% is from harvesting and post-harvest processing; the remainder is from land preparation and tending mungbean during the growing season. This money is spent on food, clothes, school fees, livestock inputs, social occasions, health and more and is seen by both women and men as important to family welfare. Mechanizing mungbean harvesting will, therefore, eliminate around one-fifth to one quarter of women's annual income. There are almost no other opportunities for women to generate off-farm livelihoods in Village 1 since all potential ideas (e.g., grocery, livestock, tutoring and tailoring) have long been realized, and, since this is a poor community, sales opportunities are limited. Hired women who have lost work harvesting mungbean explained that they are now foraging for wild food, including diving for snails.

Village 2 in Myanmar is different. It benefits from being close to a vibrant town as well as a home-cottage-based rope-making industry. Many women take advantage of these opportunities, but again married women with small children find their options restricted and therefore mungbean harvesting remains an important source of income for them. Overall, however, the implications of mechanically harvesting mungbean are likely to be less serious with women experiencing around 10% loss in income.

However, mungbean harvesting is the only paid fieldwork option open to women in Village 3 in Bangladesh. Men explained that "Women only work in the month of May. Their male partners do not allow them to work in other months" (Village 3, hired labor men, Bangladesh). In Village 4, mungbean is the most important crop to women laborers though a few work as maid-servants, in chili and vegetables and in making fish traps for sale. Interestingly, men in Village 4 did not discuss this other work and claimed that women only pick mungbean. In Village 4 particularly, men reiterated the importance of women having sufficient time for household tasks and childcare as a reason for not overburdening them with fieldwork, and, in both Villages 3 and 4, men cited restrictive social norms which limit women's mobility and work beyond the home. Even so, when women in Village 4 were asked about what they would do if mungbean harvesting were mechanized, they thought they could rely on making fish traps, work as maid-servants and other forms of minor income generation. Interestingly, they saw an opportunity. "We want to adopt mechanization. We have to learn how to operate machinery. We will learn from each other then we will operate it. We want to get training from agricultural research organization" (Village 4, hired woman, Bangladesh).

Is such a seemingly radical idea possible? Discussions around gender equality and social norms showed that considerable change has been experienced over just a few years in Villages 3 and 4 in Bangladesh in many areas of life. Most—but not all—men respondents openly espoused gender equality and said they practiced it in their daily lives, for example, through sharing food equally, ensuring everyone is well-clothed and through listening carefully to women's views in intra-household decision-making. In these communities, gender norm change is reflected in high rates of girls being schooled and the presence of women teachers. One of the most visible changes is women moving into fieldwork, with mungbean being the most important example of this in the two villages studied. Paid fieldwork in mungbean for women began around a decade ago. Smallholder farms began to find it difficult to cover labor requirements due to extraordinary increases in productivity. This is attributable to the use of improved varieties and technologies and ever-expanding markets both locally and further afield (Community Profile, Villages 3 and 4, Bangladesh). Although social norms initially hampered acceptance of women working in the fields, today "Society honors women who work as hired agricultural labor. They respect us. They know we are working for the family. If you can give a contribution it raises your prestige. People look at you in a different way", explained one woman (Village 3, hired worker woman, Bangladesh). Such women also experience more political voice in the community, being able to take their issues to the village council and expecting to be listened to. The money earned from mungbean harvesting is used to meet a variety of needs, with the most important being children's education. This is particularly important for boys who do not receive a government stipend (unlike girls). One woman said, "*My children are my dream and my life. I invest my income and my life in both of them. I pray they won't be like me. They'll create a position for themselves in society"* (Village 3, hired worker woman, Bangladesh).

Personal visions created by landless participants in Myanmar focused not only on their personal and family hopes for the future, but also poignantly (given their poverty) highlighted their longing to provide benefits to the whole community: a bridge, donation to a feeding center for poor children, a clinic and a pagoda. However, it is almost impossible for hired laborers to provide these benefits. Women explained *"We try hard to contribute to the wellbeing of the community, but we have little time and leisure to relax. We only have an average of 15 days income per month and the other days we are always busy in mind trying to find work and money"* (Village 1, hired worker woman, Myanmar). In Bangladesh, men laborers in Village 3 said they tried to contribute by helping to repair roads and building mosques. Women laborers in Village 4 described contributing towards religious programs.

8 Impacts

8.1 Scientific impacts – now and in 5 years

In Pakistan, the herbicides available which could be used as desiccants include Paraquat (Gramoxone), Glyphosate, 2,4-D, Pyraflufen, Thidiazuron, Cyclanilide, Stance (Cyclanilide+Mepiquat chloride) and Thiourea. In Bangladesh, Paraquat, Glyphosate, MClore 5G (Butaclore), Superhit 500 EC (Pritilaclore), Superpower 10 WP (Pyrajosulfuran-Ethyl), Supermix 18 WP (Bensulfuron), Methayl 4 % + Acetaclore 14 %), are used in rice cultivation. In addition, Supercare 25 EC (Oxadizone), Fielder (2,4-D Amine), Paraxon 20 SL (Paraquat), Sun-up 48 SL (glyphosate), Release-9 EC (Phenoxapropo-p-Ethyl) are used as herbicides in the cultivation of potato, onion, rubber, tea, jute, chili and mungbean. However, in Myanmar, Glyphosate is the major chemical in use as a general herbicide. We had unanimously decided that the project will not work with Paraquat, due to safety concerns. In Bangladesh and Pakistan, four desiccants (Glyphosate, Ethrel, Urea and Thiourea) and in Myanmar, three desiccants (Glyphosate, Ethrel and Urea) with two dosages were investigated. Ethrel used in Myanmar was sourced from Thailand. Due to the increasing concerns on the use of Glyphosate, the project needs to research for safer and better alternative(s) is required. **The preliminary studies conducted in the project suggest the possible use of Urea, Thiourea and Ethrel as desiccants.** However, this needs to be confirmed from the ongoing trials, with different concentrations.

Chemical residues in mungbean seed: Samples collected from field trials of three countries were analysed for respective chemical residues and compared with standard (globally accepted) permissible limit (prescribed by EU and APEDA). Residue Analysis: The seed samples harvested from field trials (3 countries) were analysed for chemical residue. Out of 130 (60-Pakistan, 30-Bangladesh & 40-Myanmar), 40-45 samples were used for each desiccant. **No traces of chemicals were detected in the seed samples, except in 9 samples.** In these samples traces of Glyphosate higher than the permissible limit was observed.

During the IMIN Annual Meeting, 3 May 2018, the field visits to mungbean varietal and seed increase trials on local research farms in Myanmar demonstrated the significant range and variation in mungbean architecture, population density and row orientation/spacing. These issues have significant and challenging implications for the progress and validity of harvest mechanization trials, comparisons, harvest process improvements and subsequent evaluation. It was also observed that at one of the Agricultural Mechanisation Department (AMD) district depots in Myanmar, the stock in the parts store included the components to construct two factory supplied edible bean modification kits to suit Kubota DC 70 G harvesters, which make up the majority of AMD's relatively extensive harvester fleet. In discussion with the Department and Depot Management, it was apparent that at least one Kubota DC 70 G harvester was likely to have the edible bean kit fitted during the current harvester refurbishment project, presenting a significant opportunity for improvement in mungbean harvesting and a comparison with other local harvesters and methods during the upcoming mungbean harvests.

In Myanmar, preliminary trials have shown the advantages of the use of fine-tuned harvesters during the dry season. In addition, the choice of the variety (synchronous maturing) is also critical. Machine harvesting alone (Kubota with modifications) had the least seed loss, followed by manual harvesting (twice) plus machine harvesting. However, broken seed percentage was the least in manual harvesting (twice) followed by machine harvesting alone. There was no difference in the germination of the harvested seeds among the different treatments.

8.2 Capacity impacts – now and in 5 years

Capacity development of the local partners included a training of interested staff of Yezin Agricultural University in data collection software and the participation of the Myanmar staff in two trainings on gender and inclusive business development. Trainings on the basics of qualitative research, qualitative data collection, and the concept of gender in it, raised the ability of the socioeconomic teams in Myanmar and Bangladesh to conduct research on gender. The training supported the understanding of qualitative research concepts and enables easier cooperation between the mostly quantitatively working teams in Bangladesh and Myanmar with qualitatively working colleagues. This better understanding for the research of team colleagues is substantial in combining the insights of the different disciplines.

In Pakistan, five demonstration plots (0.4 ha each) were sown in Bhakkar district in which 5 progressive farmers and 2 service providers were trained for seed production (integrated crop management) and mechanized harvesting. Five demonstration plots (0.4 ha each) were sown in Chakwal district and 25 smallholder farmers were trained on integrated crop management of mungbean for higher production under rain-fed conditions. Over 450 farmers, researchers, extension workers, NGO-NRSP, harvesting service providers, and seed companies were demonstrated/trained for mechanical harvesting through field days, training programs and awareness seminars.

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8.3 Community impacts – now and in 5 years

8.3.1 Economic impacts

Involvement of the private sector in the project in Bangladesh

In Bangladesh combine harvester usually used for rice harvesting. Mungbean harvesting through combine harvester was the first time for Bangladesh initiated through this project. Two private companies i.e. ACI motors and The Metal Pvt. Ltd were involved in this project for mechanized mungbean harvesting. Private sectors use 4L-BZ 110 KYM machinery and Daedong models of combine harvesters and provide service to harvest the rice. A limited number of combine harvester were available at the experimental site. Initially, PRC BARI contacted service providers to harvest the mungbean crop with their combine harvesters and the service providers were concerned for damage to their combine harvesters due green foliage of mungbean even at maturity. Another major reason for the non-involvement by the Private companies was that the farmers have still not widely adopted combine harvesting for rice therefore harvesting mungbean with machine was a big question. The multiple rounds of meetings and discussions helped them to understand that this research for improved mungbean seed production system through mechanized harvesting will help to expand their services from rice to other legume crops such as mungbean. When service provider understood that the finding will useful for their business, then they agreed to test the harvesters for mungbean without any kind of modifications therefore the harvesting was tried with the existing settings used for cereals. The service providers also tried this on large scale at farmers' fields in mungbean growing areas.

Field trial on combine harvester was conducted at Rangpur Research Farm and Pulses Research Centre, Ishurdi during *Kharif 1*, 2018 and 2019. Participants including researchers from PRC, BADC officers and The Metal Pvt. Ltd to observe the mechanical harvesting in mungbean through combined harvester. The project conducted field days to demonstrate of mechanized harvesting (Figure 22 & 23). During field demonstration at PRC Ishurdi, besides service provider, 25 stakeholders including large scale seed producers e.g. BADC, ACI seeds, progressive farmers and local NGO's had participated. Under this project, PRC produced 1.5 ton seed of BARImung 6 for demonstration at farmer field for the year 2020-21.

The trial was started at PRC, Ishurdi and Rangpur to demonstrate the mechanical harvesting with full feed harvester during *Kharif-I* season, 2020 and 21. During this season due to COVID-19 pandemic, there was a nationwide lockdown, therefore, the demonstrations couldn't be undertaken. The PRC, BARI will receive a combine harvester with bean kit A and B, model YH 700 (Yanmar 700). This will provide an opportunity for large-scale demonstration at farmers' fields in mungbean growing areas.

Figure 22 Field trial on mechanical harvesting of mungbean at Rangpur Research Farm during *Kharif I*, 2018

Figure 23 Mungbean farmers, seed producers and researchers evaluating combined harvester at Pulses Research Centre, Ishurdi during *Kharif I*, 2019

Involvement of the private sector in the project in Myanmar

Private sector players working for hiring services for harvesting cereals were involved during the project. These private sector players offer harvesting services for rice harvesting during the monsoon season. In post monsoon season, through some modifications and changing with bean kit, they also offer harvesting services to pulses growing farmers such as (mungbean, black gram and chickpea (if tall plant) in the future. In Yangon region, mungbean cultivation is done during post-monsoon season where the crop is being harvested by combine harvester through harvesting service providers in hubs. The private companies are keen to take up mechanical mungbean harvesting in different mungbean growing areas. The local farmers and DOA Extension staff, AMD staff from local Township were invited to see the mechanical harvesting in mungbean. A new seed company i.e. Patama seed was recently established. The Patama seed Co. take up mungbean seed production with farmers through contract seed production at Bago region during the post-monsoon season and Sin Pyu Kyun (Magway region) in pre-monsoon season with irrigation. The company provides high quality registered seeds and inputs in advance and buy-back the mungbean with 5% more than the local price. The Patama Seeds showed interest in using mechanical harvesting.

A field was conducted at Tatkone Research Farm on August 4, 2018 with over 50 participants including researchers from DAR & YAU, extension officers from DoA, officers from AMD, mungbean growers and seed producers to demonstrate the mechanical harvesting in mungbean through combined harvester (Figure 24 & 25).

The third year of the project (2020) was greatly impacted with COVID-19 pandemic through the nation-wide lockdown. Therefore, the trial conducted at Chaung U Township during 2020 to demonstrate the mechanical harvesting to Greenish Sagaing Region Seed Production Association could not be harvested with machine due to lockdown in the country. The another attempt to conduct mechanical harvesting demonstration trial at Minbu Township with collaboration DOA was also unsuccessful due to continuous rains after desiccant application at 85% pod maturity. There were no demonstration trials and field days conducted in 2021 due to increasing cases of COVID-19 during crop season and lack of budget owing to the unstable political situation.

Figure 24 Demonstration of mechanical harvesting in mungbean through modified cereal harvester at Tatkone Research Farm, Tatkone, Myanmar on August 04, 2018.

Figure 25 Mungbean farmers, seed producers and researchers evaluating the seed quality harvested through modified combined harvester at Tatkone Research Farm, Tatkone, Myanmar on August 04, 2018.

Pakistan:

The finding of trials under the project at research institutes need to be tested on large scale at farmers' fields in mungbean growing areas. For this purpose, demonstration plots were planted in Chakwal (under rainfed conditions) and Bhakkar (under irrigated conditions) Districts. Improved production technology of mung bean was used to grow the demonstration plots. For mechanized harvesting private sector (service providers) were involved by the project. In Pakistan, service providers use older models of New Holland combine harvesters (8060, 8070, TC-55, TC57, TC56, 1540, 1550, Semeca and Leverda) and they provide service to harvest the wheat and rice.

Initially when service providers were contacted to harvest the mungbean crop with their combine harvester machine they were reluctant to use their harvesters for harvesting of mungbean crop to avoid any possible damage to their combine harvesters as they were concerned about the green foliage of even a matured crop. However, the project team briefed them about our experimentations at NARC, Islamabad that how we can dry this foliage before harvesting and what changes we can make in settings of combine harvester to avoid not only the risk of any damage but also to get better quality grain. One service provider agreed and started work with the project team at one demo plot in District Bhakkar and one in District Chakwal. Both service providers were engaged during the application of desiccant and modification of setting of combine harvester. After 7 days of application of desiccant mungbean plot was harvested with combine harvester by service providers. Project conducted field days to demonstrate the mechanized harvesting to different stakeholders like service providers, farmers, agri extension workers and representatives of NGO's. After successful demonstration, mungbean farmers and service providers started adopting this technology to reduce the risk of grain damage due to erratic rains at the time of harvesting. At present, five service providers (4 in Bhakkar and 1 in Chakwal) have adopted this technology and are providing services to farmers. The private sector players who participated in different project activities are listed in Table 32. NARC in collaboration with PARC Agro. Tech Company has undertaken mungbean seed production.

Table 32 Private Sectors Involvement for adoption and upscaling of mechanized harvesting in the country

Sr. No.	Name of Service Provider	Address	Contact No.	No. Harvester available
1	Ali Raza	Nashaib Hassainabad, Bhakkar	+923336841343	2
2	Muhammad Imran	Nashaib Hussainabad, Bhakkar	+923467583021	2
3	IhsanUllah	Mithu Bindu, Bhakkar	+923447966038	1
4	Rana Gulzar Hussain	Karor Nashiab, Layyah	+923461065577	1
5	Muhammad Arif	Bhakkar	+923027966575	2
6	Khurram	Bhakkar	+923458053636	1
7	Qasim	Bhakkar	+923017951515	1
8	Azhar Ahmad	Mulhal Mughlan, Chakwal	+923009854271	2

8.3.2 Social impacts

The project did not have social impacts but has generated important information about the potential and future social impact of the mechanisation of mungbean harvesting.

8.3.3 Environmental impacts

The project did not have an environmental impact but contributed to understanding the effectiveness of options which in the future may impact the environment.

8.4 Communication and dissemination activities

In Pakistan, field day was conducted on 24 August 2019 in Bhakkar district for the dissemination and awareness of mechanized harvesting of mungbean in collaboration with Arid Zone Research Institute, Bhakkar. Fifty farmers attended the field day. Field day and demonstration of mechanized harvesting at farmers' field convinced farmers to adopt this intervention, which saves time and money. Now farmers have started adopting this technique for the harvesting of mungbean. Economic evaluation (Comparison between methods) showed that the farmers would get a benefit of 10,000 PKR (86.23 AUD /ha by adopting mechanized harvesting.

Progress made in the project has been covered in the ACIAR Partners Magazine (2020) Issue I: https://reachout.aciar.gov.au/sprouting-a-new-market-through-mungbean-research

9 Conclusions and recommendations

9.1 Conclusions

9.1.1 Impact of mechanical harvesting on women and men farmers

The research hypothesis of that the (potential) impacts of mechanizing mungbean harvesting are likely to weaken women hired workers' economic and personal empowerment. The data broadly confirm the hypothesis. However, there are likely to be differences in impact within and between Myanmar and Bangladesh. Mechanization is an inevitable process, and will remove an important source of income for women, and to a lesser extent men laborers. In our two Bangladesh research sites, harvesting mungbean is the only fieldwork task open to nearly all of the landless women we met. They are otherwise restricted to engaging in time-consuming cottage industries with low profit margins, or working unpaid on the family farm and in the home. In Myanmar, in Village 1 women earn between 50% to 100% of their annual agricultural income from mungbean and 20%–28% of this is from harvesting and post-harvest processing. In contrast, the impacts may be less serious in Village 2 as women may experience around 10% loss of income.

Will women be able to substitute this income? The evidence unsurprisingly suggests that the impact of mechanizing mungbean harvesting is likely to differ according to the relative degree of alternative on- and off-farm income generating opportunities available locally and nationally. Village 1 in Myanmar experiences low on-and-off-farm economic diversity. Gender norms mean that men are far more likely to find work in local off-farm industries and services than women, particularly married women with families—who form the bulk of hired laborers. In Village 2, though, women are, potentially at least, more likely to be able to find alternative sources of income. The site benefits from broader on-farm crop and livestock diversity than Village 1, and a much wider range of potential income-generation opportunities locally. Over 70% of women have already moved out of agriculture and gender norms are shifting to accommodate this. Even so, married women may find it harder than their daughters or single peers to find other forms of income.

Our data indicate that a dynamic economic environment per se is insufficient to allow women to take up alternative opportunities. The literature review noted that typical local off-farm opportunities, such as construction and carpentry, tend to benefit men in Myanmar due to the gendered construction of labor. In Bangladesh, the gendered construction of local labor opportunities is more constrained still, with the added constraint that women's mobility—which is part of a broader set of patriarchal concepts around women's roles and what they should be and do—is severely restricted. Furthermore, women we met in both countries are primarily mothers, charged with household and care work, and this is another factor that contributes to their lack of mobility. This means that women in both countries, with few assets of their own, are largely confined to seeking, or building, economic opportunities within their own communities. This is a challenging task. In Bangladesh, opportunities for women in off-farm work appear to be stagnating after a period of sustained growth, and women are mainly concentrated in low-paid insecure jobs rather than moving into white collar jobs.

What would a loss of income mean for the women respondents? A lower contribution to household income may reduce their voice in intra-household decision-making. The important support that women in the Bangladesh sites can provide to their children to enable them to stay at secondary school, and into tertiary education, may no longer function. Gender norms around "what is possible" for women may potentially become more rather than less restrictive as women are pulled out of the field. In locations such as Village 2 in Myanmar, where women are already pushing the envelope, and where alternative employment exists for many, mechanization may simply speed up the pace of change. Even so, it is probable that not all women will have the skills, time or capacity to adapt (otherwise they most probably would have moved out of mungbean harvesting already). Overall, men across all sites will be less affected since their participation rates in harvesting and post-harvest processing are low. Also, men are less restricted by gender norms and can travel freely to find work elsewhere. This said, the women and men respondents to this study have an extremely low asset base and they have, up to now, lacked the resources to invest in alternative forms of income generation, including outmigration. In all four study sites, women find it harder to innovate than men. Men rather than women are framed as innovators, and so it is simpler for men to accrue family and community level support, and financial resources to innovate.

Income is not the only proxy for empowerment. The human development approach, measured in the Human Development Reports, considers the object of development to be about expanding the capabilities of individual women and men to define and live the lives they want to have. In this shift from desire to realization, people move from having a potential of being, and doing, into actually being able to be, or to do. Our data suggest that respondents make clear associations between doing, and being, and income. Women shared ways in which their income benefited their families, for example in Bangladesh through supporting their children's education. They also shared ways in which their lack of income hampered their ability to participate effectively in community-level practices, including religious observance. Research conducted in Cambodia showed that rather than seeking personal autonomy, women see empowerment as an outcome of contributing to, and gaining respect from, others, including partners, the wider family and the community. Our findings echo this understanding.

9.1.2 Status of mechanical harvesting in project partner countries

Bangladesh: In Bangladesh, mungbean was harvested several times by hand picking at pod maturity which is very labor-intensive. About >50% cost involve for harvesting considering total production cost. Bangladesh has a priority of mechanization for improving productivity and profitability. The research efforts on mechanical harvesting of mungbean through this project are the first of its kind in Bangladesh. Machine harvesting using modified cereal harvesters was carried out by lending from the private companies (ACI motors and The Metal (Pvt) Ltd. Although the harvester used for experiments was from a private company with limited scope for modification, the initial efforts generated critical understanding on mechanical harvesting in mungbean. For the Mungbean harvesting, the challenge was to dry the crop completely suitable for combine harvester. It is generally necessary to apply a chemical desiccant to the crop prior to mechanize harvesting. Although some work had been done in Meherpur and Chuadanga district but little is known about the fate of the chemical desiccants and whether there are potential problems with residues in the soil or in the produce and also the exact modified settings of cereal combine harvester for mung bean. BARI has teamed up with ACI Motors Ltd and will promote the use of Yanmar YH – 700 (with bean kits) for mungbean harvesting. The bean kit A: bag type and tank-type both are adapt that don't crush bean and threshing parts can be selected depending on crop size. Another Bean Kit B is to reduce crop stain and damage is also adapted which is suitable for tank type. The testing of the new harvester with different treatments in research farms and farmer fields will give more information on whether any fine-tuning is required, before scaling up. The variety × season interaction will be further studied for precise recommendations to farmers and harvesting service providers. The already established links will help to promote this activity with seed companies in the first place.

The project started initial efforts for mechanical harvesting of mungbean is in Bangladesh. The Pulses Research Centre, BARI need some improvement for finalization and recommendation. PRC, BARI will continue work with project findings from core research activities. The mechanized harvesting of mungbean along with detailed methodology will be finalized involving different projects and seed producers to disseminate the results of this project. Apart from these capacity building of different stakeholder's *viz.* progressive farmers, extension workers, service providers and public and private seed companies for integrated crop management, seed production, and mechanized harvesting of mungbean will also be needed and undertaken by the NARS partners.

Myanmar: Harvesting with the modified machine is progressing well during the dry season at the Yangon region. Although the losses are slightly high, farmers from Yangon region accepted machine harvesting because of huge labour shortage at harvest time. Most of the labour work in Yangon comes from Central Dry Zone. Harvest hubs were formed with progressive farmers and harvesting contractors in this region. The practice can gradually be scaled up to other mungbean growing regions with the support of the DAR Agricultural Mechanisation Department (AMD) and harvesting service providers. The finding of the chemical desiccation experiment indicates the potential use of desiccants like ethrel and urea during the rainy season as an option. The variety × season interaction could be further studied for precise recommendations to farmers and harvesting service providers.

The videos of mechanical harvesting have been captured from Sebin and Tatkone trials. These videos were broadcasted through farmer channels and social media such as Facebook to create awareness among farmers, harvesting service providers and other stakeholders. Most of farmers and seed producers' associations are interested to accept the mechanical harvesting for mungbean. The further demonstration of project findings will be continued by DAR and other NARS partners, seed production associations and harvesting service providers across different locations.

Pakistan: In Pakistan, the work on mechanized harvesting of mungbean had begun during 2014-15 under the USAID-funded Agricultural Innovation Program (AIP) by Pakistan Agricultural Research Council (PARC) in collaboration with WorldVeg country office in Pakistan. Traditionally mungbean was harvested several times by hand picking of pods when dried down. This resulted in a high-quality grain but was very labor-intensive. As labor costs increased this has been replaced by cutting the whole plant by hand, letting it dry in the field, and machine threshing. This is still relatively expensive and exposes the grains to rain damage. Machine harvesting using modified cereal harvesters is much faster and has been used for decades in different countries like Australia. Different machines (tractor mounted side cutter bar, wheat reaper etc) were tested to harvest the mungbean crop but resulted in higher grain losses. Due to indeterminate growth habit of mungbean its pods become matured and dried but leaves and stem remained green and succulent. In previous research in India it was shown that small-scale wheat and rice harvesters can be modified to effectively handle mungbean, but it is generally necessary to apply a chemical desiccant to the crop prior to mechanized harvesting to avoid the buildup of gummy residues of plant sap in the harvesters. So the biggest challenge was to dry the crop completely to harvest mechanically with combine harvester. Various chemicals were tested to desiccate the crop, paraquat (@1000-1200 ml/acre) gave good results to dry the crop within 4-6 days. Cereal (wheat) harvesters are very commonly available in Pakistan, we tried this combine harvester to harvest mungbean after dry down the crop with paraquat. Although some work had been done but little is known about the fate of the chemical desiccants and whether there are potential problems with residues in the soil or in the produce and also the exact modified settings of cereal combine harvester for mungbean.

In this project we started work on various desiccants are usually available but not all desiccants are equally effective and not all are equally safe to farm workers and consumers. Therefore, the project worked to assess what combinations of available chemical desiccants and application methods are the safest and most effective for mungbean. Experiments were conducted at National Agricultural Research Center (NARC), Islamabad and Arid Zone Research Institute (AZRI), Bhakkar. Chemical residue analysis of grains was also done to study the residue effect of chemicals used as desiccant. The desiccant combination Glyphosate 0.3% + 1% Ammonium Sulphate was proved very effective in drying down the mungbean foliage within seven days after application.

New Holland harvester TC-5040 was used in trials conducted at NARC, Islamabad. Modification in terms of drum speed (reduced from 850 to 650 rpm), fan speed (increased from 800 to 1000 rpm) was proved very effective and the grain breakage losses reduced from 26% to 6%. The NARC is actively promoting mechanical harvesting through on-farm demonstrations to progressive farmers and farmer organizations. There is good links already made with seed companies, farmer groups and harvesting service providers. As mungbean residues are being used as livestock feed in some mungbean growing regions, the use of reapers followed by threshing is also a good option for farmers. The variety × season interaction could be further studied for precise recommendations to farmers and harvesting service providers.

The recommendations for mechanized harvesting of mungbean along with detailed methodology will be finalized and distributed to all stakeholders. National Agriculture Research system (NARS) involving different projects and community-based NGOs to disseminate the results of this project through:

1. Upscaling the adoption of mechanized harvesting technology by front line demonstration plots in other mungbean growing areas of the country.

2. Capacity building of different stakeholders like agronomists, farmers, input suppliers, and community-based NGOs, extension workers, service providers and public and private seed companies will be continued for integrated crop management, seed production and mechanized harvesting of mungbean.

9.1.3 Moving Forward

The dilemma explored here is the fact that mechanization of mungbean harvesting, which is inevitable because it reduces farmers' costs and increases profits, may well do harm to potentially hundreds of thousands of women laborers who rely on harvesting mungbean for an important part of their income. Given this scenario, development actors need to take mitigating action. Investing in women's capacity, helping them to develop small and medium-scale enterprises (SMEs), and assisting them in entering new forms of work is important. However, such activities do not challenge the underlying issue constraining women's ability to take charge of their destinies. This is that gender norms strongly determine appropriate behaviors for women and underpin local assumptions of which work is considered suitable for each gender. One way forward is to invest in gender transformative approaches. These aim to stimulate change in norms and associated behaviors to make a wider range of choices possible. Gender transformative approaches target gender relations rather than women, or men [48–50], to facilitate transformation. They aim to ensure that men as much as women benefit from transformation and to ensure that the whole community sees the benefits. We show how this could happen in Figure 26.

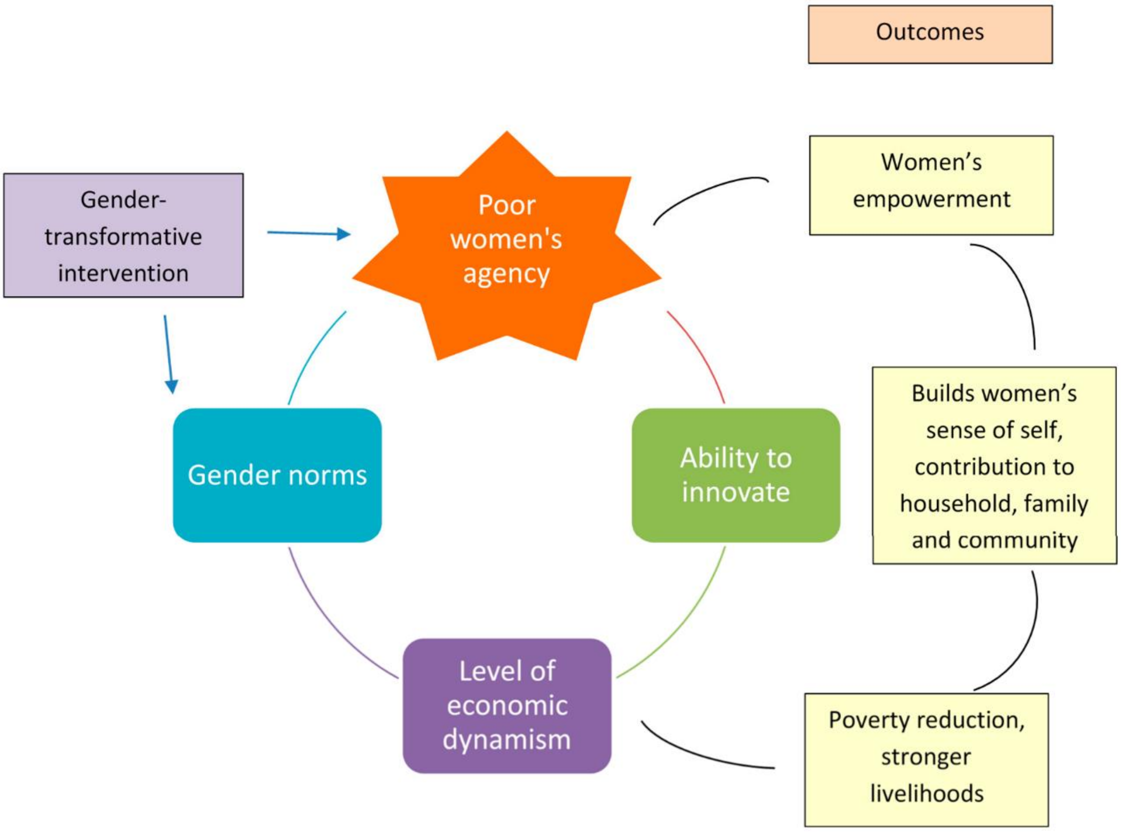

Figure 26. Strengthening women's agency

First, we hypothesized that mechanization of the mungbean harvest would reduce labor costs and thereby increase smallholder farm income. Second, we hypothesized that mechanized harvesting removes a source of drudgery from men and women in the farm household. Third, we hypothesized that mechanization eliminates an important income stream for hired women and men laborers. We expected that these hypotheses would allow us to consider potential gender tradeoffs between smallholder farm income, smallholder farmer well-being and hired labor well-being should mechanization occur.

Contrary to our first hypothesis, the ex-ante partial budget analysis suggests that reduction in the cost of labor is currently not a major motivation for mechanization. This is due to the relation between the assumed cost of mechanized harvesting and hand harvesting, as well as due to the substantial yield losses associated with the reduction of harvests. However, this may well change over time. Rising labor costs, the likelihood of reduced costs of mechanized harvesting and the introduction of new mungbean varieties with synchronous maturity is expected to improve the profitability of mechanization. Increases in average profits are also not the only motivation for farmers to adopt mechanization, as we showed that farmers in both countries are primarily motivated by the need to reduce their exposure to imminent weather risk: to ensure timely harvesting in the face of rain or flood. The labor intensity of mungbean harvesting means it can be difficult for all farmers to secure enough labor at the same time. Women smallholders outlined further benefits of mechanization; in particular, they need to prepare food for the hired workers, which consumes time and money.

Our second hypothesis is that hand-harvesting mungbean is perceived as an arduous and time-intensive task. Mechanization is thus expected to reduce levels of effort. This is verified. Despite the relatively small involvement of family members in hand-harvesting mungbean, the reduction in drudgery provides smallholder farm families with an additional motive for mechanization. Women and men highlighted other important benefits. In Myanmar, these related specifically to the ability of the respondents as individuals to contribute to the well-being of the community through performing good deeds. Such actions can strengthen personal social capital and build community social cohesion. Merit making is important within Buddhist cosmology—it builds a ritual economy of merit based on spiritual rewards for material donations. In the context of Myanmar, Dove argued that giving trends in Myanmar (the highest in the world) are also a response to low government investment in basic social services and high levels of deprivation.

Finally, the results support the third hypothesis that mechanizing the mungbean harvest could remove vital income from the particularly vulnerable group of hired landless women. The qualitative data show that mungbean harvesting offers women, particularly married women, and a very large percentage of their income. Women use this income to meet immediate household needs and invest it in their children's education, thus providing intergenerational benefits. In Bangladesh particularly, women noted that earning an income, modest though it may be, has elevated their standing at community level and enabled them to be seen and heard in community level forums. In Myanmar, women workers already find it difficult to accrue merit through giving, and this challenge is likely to deepen should they lose work through mechanization of mungbean harvesting.

9.2 Recommendations

Mechanical harvesting requires that green leaves and stems be desiccated before harvest. The assessment of the suitability of desiccants to aid mungbean harvesting revealed that Thiourea (10%), and Thiourea (15%) are effective and offer alternatives to farmers. This is significant as concerns on the use of glyphosate in farming is increasing in some countries.

It was found that the cereal harvesters currently available in the project countries are too aggressive for harvesting mungbean and needed modifications. In Pakistan, significant progress has been made in modifying New Holland TC 5040 Harvester in reducing seed losses and NARC is actively promoting mechanical harvesting through farmer organisations. In Myanmar, harvest hubs have been formed and are actively using Kubota DC 70 G fitted with bean kits for hiring by farmers. BARI has teamed up with ACI Motors Ltd and will promote the use of Yanmar YH – 700 for mungbean harvesting.

In Table 33, season-wise variety and management recommendations for the farmers and harvesting service providers in the three partner countries are presented.

The identification of a mungbean accessions with natural leaf senescence ability at pod maturity offers hope in the development of future varieties which would not require the use of chemical desiccants. These varieties will be extremely valuable to the high premium sprout market segment.

Farm mechanization can promote the economic sustainability of small farms and in the context of cereal-legume systems strengthen plant protein-based diets, which support human health and environmental sustainability. However, mechanization inevitably displaces hired laborers who depend on manual farm work for their income. Few studies have systematically analyzed the differential effects on women and men hired labor. Here, we used primarily qualitative data from Myanmar and Bangladesh to test the hypothesis that the effects of mechanizing mungbean harvesting—which is now commencing in both countries—are likely to weaken women hired workers' economic and personal empowerment. The study focussed on rural landless women laborers as an important part of the agricultural labor force. The results broadly confirm the hypothesis, although there is variation between the research sites. Harvesting mungbean is the only fieldwork task available to many landless women, particularly married women with children, in both countries. Gendered restrictions on women's mobility and their role as family caregivers, as well as norms about appropriate work for women and men, restrict women's options regarding alternative work both locally and further away. The effects are likely to be particularly negative in locations with minimal off-farm economic diversity and more restrictive gender norms. Overall, men across all sites will be less affected since their participation rates in harvesting and post-harvest processing are low. They are less restricted by gender norms and can travel freely to find work elsewhere. However, women and men in low asset households will find it problematic to find alternative income sources. Less restrictive gender norms would help to mitigate the adverse effects of farm mechanization. It is important to invest in gender-transformative approaches to stimulate change in norms and associated behaviors to make a wider range of choices possible.

The study analysed, ex-ante, the likely social and economic trade-offs of mechanizing the mungbean harvest in Bangladesh and Myanmar. We used a mixed methods approach combining survey data from 852 farm households with in-depth interviews in four villages. Partial budget analysis shows that mechanical harvesting of mungbean is not yet profitable for most farms. There is nevertheless an incentive to mechanize as the associated timeliness of the harvest reduces the risk of harvest losses from weather shocks. Men and women farmers expect time savings and reduced drudgery. The results confirm that hired workers depend on manual harvesting for income and status in both countries. Most hired workers are landless married women with limited access to other sources of income. In the short term, farmers are likely to combine manual harvests and a final mechanized harvest of the indeterminate crop. This could mediate the impact on hired workers. However, in the long term, it will be necessary to facilitate income-generating opportunities for women in landless rural families to maintain their well-being and income

Table 33. Season-wise variety and management recommendations for the farmers and harvesting service providers

Country	Season/location	Variety	Management	Recommendations
Myanmar	Yezin 1	Sowing time- 1st to 15th November Seed rate-35-40 kg/ha Broadcasting	The mechanical harvesting without desiccant application works well with this variety in Yangon region	The mechanical harvesting without desiccant application works well with this variety in Yangon region, and Kubota DC 70G fitted with bean kit
	Yezin 11	Sowing time- July to August Seed rate- 25-30 kg/ha Line sowing (distance between lines)- 45 cm	Only mechanical harvesting with desiccant application at maturity	Only mechanical harvesting with Kubota DC 70G fitted with bean kit and with desiccant application (Glyphosate 0.3% + ammonium sulphate 1%) at maturity
	Yezin 14	Sowing time – March Seed rate- 25-30 kg/ha Line sowing (distance between lines)- 45 cm	One hand picking + mechanical harvesting with desiccant application	One hand picking + mechanical harvesting Kubota DC 70G fitted with bean kit and with desiccant application (Glyphosate 0.3% + ammonium sulphate 1%)
Bangladesh	Gazipur and Ishwardi	BARI mung 6 & 7	Sowing time- 1st to 15th March Seed Rate 30-35 kg/ha	Mechanical harvesting with desiccant application at maturity

			Line sowing with 40 cm distance IPM and IDM for pest and disease management	
	Madaripur	BARI mung 6	Sowing time- 15 to 25 February and 1 to 15 August Seed Rate 30-35 kg/ha Line sowing with 40 cm distance IPM and IDM for pest and disease management	The mechanical harvesting without desiccant application works well with this region in post-monsoon
	Rangpur	BARI mung 6	Sowing time- 15 to 30 March Seed Rate 30-35 kg/ha Line sowing with 40 cm distance 1-2 irrigations and weedings IPM and IDM for pest and disease management	Mechanical harvesting with desiccant application at maturity
Pakistan	Islamabad	NM 11 and NM 16	Sowing time- June end to Mid-July Seed rate- 30 kg/ha Line sowing with 30 cm distance IPM and IDM for pest and disease management Rainfed cultivation One spray after 21 days of crop emergence	Mechanical harvesting (New Holland Combine harvester with drum speed 640-670 rpm and fan speed @1000rpm) with desiccants application (Glyphosate (0.3% + Ammonium Sulphate 1%)) should be used for increased profitability
	Chakwal	NM 11		
	Bhakkar	NM11 and AZRI Mung-2018	Sowing time- April end to Mid May Seed rate- 30 kg/ha Line sowing with 30 cm distance IPM and IDM for pest and disease management 3-4 irrigations	Mechanical harvesting (New Holland Combine harvester with drum speed 640-670 rpm and fan speed @1000rpm) with desiccants application (Glyphosate (0.3% + Ammonium Sulphate 1%)) should be used for increased profitability.

10 References

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11 Appendixes

11.1 Appendix 1:

Understanding the genetics, physiological and molecular mechanism of leaf senescence trait in mungbean

Mungbean minicore accessions with natural leaf senescence were confirmed during Spring 2020 in Hyderabad (Figure 27). A field trial with five genotypes *viz.,* VI001579 BG, VI003068 A-BR, VI001191 BG, VI003658 BG, and AVMU 1690 was conducted in RCBD with four replications during rainy 2021 to understand the variability of leaf senescence and also to understand the physiology of the trait. Unfortunately, due to the continued rains at the maturity, senescence symptoms could not appear in the trial and plants started the second flush for flowers and pods. Therefore, the same trial is being repeated in the field as well as glasshouse conditions during the post-rainy season to understand the trait better (Figure 28).

Figure 27. Mungbean minicore accession with natural leaf senescence (VI001579 BG) in a field trial conducted during Spring 2020 in Hyderabad.

Genetics of leaf senescence traits

An F_2 population of a cross between AVMU 1689 × VI001579 BG with around 107 individuals was screened for leaf senescence trait during rainy 2021 to start initial efforts to understand the genetics of the trait. The leaf senescence was recorded on a 0 to 5 scale starting at the initiation of maturity (60 days after sowing) among the F_2 individuals (Table 34). The scoring done at 65 days after sowing when most of the F_2 individuals were at the maturity stage was considered for analysis. The individual plant with 0 and 1 scores were considered as non-senescence whereas the individual plants with a score of ≥2 were considered as senescence. The preliminary chi-square analysis revealed that the F_2 population fits well in the 3:1 ratio for senescence and non-senescence, indicating role of a single dominant gene. As the population size of 107 is small to conclude the findings, therefore, the F_2 population of the same cross was developed with a size of around 390 individuals. These F_2 individuals are being tested in the glasshouse from October to December 2021 (Figure 29). The DNA from each F_2 plant is isolated for further genomic studies. The $F_{2:3}$ population will be tested for leaf senescence under field conditions during spring 2022.

Table 34. Leaf senescence score recorded on an F_2 population of AVMU 1689 × VI001579 during rainy 2021.

Description	Score	Number of F_2 plants at		
		60DAS	63DAS	65DAS
All the trifoliate are green	0	58	25	13
1 to 10% trifoliate turned grey/senescence	1	38	30	12
11 to 30% trifoliate turned grey/senescence	2	10	23	20
31 to 50% trifoliate turned grey/senescence	3	1	21	27
51 to 70% trifoliate turned grey/senescence	4		7	25
71 to 100% trifoliate turned grey/senescence	5		1	10
	Total	107	107	107

Figure 28. Leaf senescence trial with five genotypes in glasshouse during post-rainy 2021

Figure 29. Generation advancement of a leaf senescence cross AVMU 1689 x VI001579 in a glasshouse during post-rainy 2021.

Table 17. Effect of mechanical harvesting on seed yield, seed discoloration, broken seeds and seed loss at Islamabad 2018 and 2019

No	Treatments	Islamabad 2018						Islamabad 2019					
		% Seed Loss*	Seed Yield (kg/ha)	% Broken Seeds	% Whole Seed	% Discolored seeds	% Quality Seed recovery#	%Seed Loss*	Seed Yield (kg/ha)	%Broken Seeds	%Whole Seed	% Discolored seeds	%Quality Seed recovery#
1	Manual (traditional) harvesting	8.70	580^{ab}	5.79^{c}	94.20^{a}	12.36	81.85	7.44	835	9.09^{c}	90.53^{a}	10.34	80.57
2	Using Cereal harvester (with glyphosate)	14.06	580^{ab}	25.59^{ab}	74.18^{bc}	9.63	64.78	6.00	918	23.68^{a}	76.25^{c}	11.43	64.89
3	Using Cereal harvester (without glyphosate)	13.71	531^{bc}	27.79^{a}	72.11^{c}	7.88	64.33	5.83	801	27.16^{a}	72.78^{c}	11.17	61.67
4	Using Modified harvester (with glyphosate)	12.15	506^{c}	22.32^{b}	77.66^{b}	7.82	69.86	6.33	866	19.22^{b}	80.73^{b}	10.54	70.24
5	Using Modified harvester (without glyphosate)	13.04	614^{a}	24.69^{ab}	75.19^{bc}	9.88	65.43	5.62	925	24.25^{a}	75.73^{c}	9.18	66.57
	CV (%)	11.94	5.81	5.55	1.72	9.40		8.16	10.94	5.66	1.50	10.17	
	SEM±	0.24	18.85	0.14	0.09	0.17		0.12	54.90	0.15	0.08	0.19	

%Quality seed recovery was calculated reducing the % seed breakage and %seed discolored from the total seed yield.

Table 18. Effect of mechanical harvesting on seed yield, seed discoloration, broken seeds, and seed loss across two years at Islamabad 2018-2019.

No	Treatments	%Seed Loss	Seed Yield (kg/ha)	%Broken Seeds	%Whole Seeds	%Discolored seeds	%Quality Seed Recovery#
1	Manual (traditional) harvesting	8.06	708	7.35	92.35	11.33	81.32
2	Using Cereal harvester (with glyphosate)	9.61	749	24.62	75.21	10.51	64.87
3	Using Cereal harvester (without glyphosate)	9.36	666	27.47	72.44	9.45	63.08
4	Using Modified harvester (with glyphosate)	9.01	686	20.74	79.19	9.13	70.13
5	Using Modified harvester (without glyphosate)	8.94	770	24.47	75.46	9.52	66.01
	CV (%)	11.73	9.28	5.61	1.62	10.02	
	SEM±	0.13	29.02	0.10	0.06	0.13	

%Quality seed recovery was calculated reducing the % seed breakage and %seed discolored from the total seed yield.

Table 19. Effect of mechanical harvesting on seed yield, seed discoloration, broken seeds, and seed loss at Islamabad during 2020 and 2021.

No	Treatments	Islamabad 2020				Islamabad 2021			
		%Seed Loss*	Seed Yield (kg/ha)	%Broken Seeds	%Quality Seed Recovery#	%Seed Loss*	Seed Yield (kg/ha)	%Broken Seeds	%Quality Seed Recovery #
1	1 hand picking + mechanized harvest with desiccant	6.00[b]	856	9.98[b]	90.00[c]	5.78	760	9.34	90.66
2	2 hand pickings + mechanized harvest with desiccant	5.77[b]	880	7.00[c]	92.96[b]	5.54	755	6.81	93.19
3	3 hand pickings	5.25[b]	861	3.23[d]	96.74[a]	5.20	740	3.11	96.89
4	Only mechanized harvest with desiccant	9.97[a]	772	18.12[a]	81.88[d]	10.30	730	17.20	82.80
	CV (%)	6.56	7.37	6.49	0.54				
	SEM±	0.10	35.84	0.11	0.03				

%Quality seed recovery was calculated reducing the % seed breakage and %seed discolored from the total seed yield.