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Impact and returns on investment of mungbean research and development in Myanmar

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Abstract

Background: There is a need for better evidence for the impact of plant breeding research on nutrient-rich crops such as pulses to guide policy-making and investment. Mungbean (*Vigna radiata* (L). Wilczek) is one of the major pulses of South and Southeast Asia and makes an important contribution to food security and agricultural sustainability. The objective of this study is to quantify impact of and returns on investment from international mungbean breeding research for Myanmar.

Methods: This study applies the economic surplus model, which is a widely applied method to quantify the economic impact of agricultural technology adoption at the aggregate level. Sensitivity analysis is used to test some of the key assumptions underlying the method. All data come from secondary sources. Estimates of economic impact are combined with investment costs to quantify returns on investment.

Results: Four mungbean varieties coming out of international agricultural research and released by the national agricultural system of Myanmar created aggregate economic gains of USD 1.4 billion from 1980 to 2016 and this is projected to increase to USD 3.7 billion by 2030. International donors and the Myanmar government invested about USD 5 million in the country's mungbean research and development over this period. The average dollar invested generated USD 92 in economic gains up to 2016 and this is expected to increase to USD 181 by 2030. The internal rate of return is 27%. There is a 20-year time lag between start of investment and start of economic benefits.

Conclusions: International research into mungbean improvement led by the World Vegetable Center has created tremendous economic impact for Myanmar, most of it accruing to smallholder farm households and laborers contributing to the mungbean harvest. The unconditional sharing of plant genetic resources between national agricultural research systems in Asia was a key contributor to the success. It is important that this culture of sharing is maintained. The finding that agricultural research investment in mungbean gives high returns supports the case for diversifying investments into nutrient-rich crops to address Asia's and the world's nutritional and environmental challenges.

Keywords: Agricultural research, Economic surplus model, Impact evaluation, Improved varieties, Technology adoption

Background

The critical role of pulses (that is, legumes harvested for dry grains) for agricultural sustainability, global food security, and healthy diets is increasingly well recognized [30, 39]. Yet, average pulses consumption is much below recommended levels in all regions of the world

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[39]. One reason for this is that yields of pulse crops have not kept pace with those of cereals and oil crops [8, 17]. An underlying reason is the relative neglect of pulses and other nutrient-rich crops in plant breeding research and policy [29].

Increased investments in plant breeding research of nutrient-rich crops such as pulses is important for food security and environmental sustainability [7, 9, 14]. Guiding such investment requires a sound understanding of the impact of past investments, but there is a lack of evidence for the impact of plant breeding research on minor crops such as pulses as most previous studies focused on staple food grains. This paper contributes to filling this gap and thereby strengthens the evidence basis for research investments in nutrient-rich crops. More specifically, the objective of this study is to quantify the economic impact of and returns on investment from mungbean (*Vigna radiata* (L). Wilczek) improvement research in Myanmar.

The study furthermore contributes to deepening our understanding of the impact of international agricultural research. Mungbean breeding programs in nearly all Asian countries are modest in size and have only small collections of breeding lines and genebank accessions. These programs therefore heavily rely on mungbean material supplied by international agricultural research centers. A recent study estimated 89% adoption of improved mungbean varieties in Myanmar with four of the top-five mungbean varieties coming from international agricultural research, accounting for 77% of the planted area in 2016 [34]. The economic impact of international mungbean breeding, as funded by international development aid, is likely to be substantial, but has never been studied or quantified.

The study's focus on mungbean is justified as it is one of the major pulse crops in South and Southeast Asia alongside chickpeas and lentils, and planted on about 5.4 million hectares (ha) across India, Pakistan, Bangladesh and Myanmar [34]. In Myanmar, the mungbean area has substantially increased from 0.04 million ha in 1980 to 0.74 million ha in 2000 and 1.21 million ha in 2016 [13]. The country produced 1.6 million tons (t) of mungbean in 2016, of which 92% was exported [27]. About 637,000 farm households in Myanmar earn income from mungbean [34] in addition to many landless households who earn income from providing labor to the harvest. In Myanmar, mungbean is grown as a single crop usually in rotation with rice. The main contribution of mungbean to food security in Myanmar is through income generation as less than 10% of production is consumed within the country. Such income is very important in a country where 30% of the rural population lives below the poverty line [12].

This paper shows that mungbean improvement research has made a tremendous impact on the incomes of mungbean farmers and landless laborers. Much of this is due to the introduction of short-duration, high-yielding varieties resistant to mungbean yellow mosaic disease (MYMD), which is the most serious disease of mungbean in South Asia. Applying the economic surplus method—a standard and widely used method based on welfare economics, we estimate that the average dollar invested generated 92 dollars in economic impact.

Materials and methods

International mungbean research

International research on mungbean improvement is led by the World Vegetable Center, which has had a mungbean breeding program since 1972. In its first decade, this program made crosses between high-yielding, disease-resistant material from the Philippines and early-maturing material from India, which led to the development and release of the improved breeding line VC1973A. This line became particularly popular in Thailand and China [19, 35], but was not resistant to MYMD, which was the main disease affecting mungbean production in South Asia.

After 1981 the program therefore focused on the development of MYMD resistance. Intensive collaboration with the national agricultural research system of Pakistan led to the identification of a local Pakistani variety with MYMD resistance. A reciprocal cross was made with VC1973A and the hybrid seed treated with gamma radiation. Backcrosses were made with other breeding lines and a large number of MYMD-resistant lines were evaluated in a shuttle breeding program between Pakistan and Thailand in the early 1990s [4, 35]. This led to two superior MYMD-resistant lines: NM92 and NM94. The first line spread rapidly in Pakistan and 51% of mungbean farmers in the Pakistan Punjab had adopted NM92 by 1994 [4]. This variety generated an economic gain of United States dollar (USD) 20 million in the Pakistan Punjab from 1992 to 1997 [4].

In Myanmar, the Department of Agricultural Research (DAR) has participated in international mungbean research since the early 1980s. DAR has released 19 improved varieties and 12 of these came from international agricultural research, of which 11 are unaltered breeding lines supplied by the World Vegetable Center. The main varieties are Yezin 9 (line VC1973A), Yezin 11 (line NM94), Yezin 14, and MAS 1. Jointly, these four varieties were planted on 77% of mungbean area in 2016 [34]. These varieties are early and uniform maturing, have erect and determinate plant types, and a high grain yield. Yezin 11 and Yezin 14 are MYMD-resistant. Yezin 9 and Yezin 11 are Cercospora leaf spot resistant. MAS

1 does not have good disease resistance, but is large-seeded and drought-tolerant. The existence of multiple mungbean varieties is an important aspect of farmers' autonomy in selecting varieties suitable to their local system [36]. The Department of Agriculture (DoA) handles seed production and promoted these varieties to farmers. These efforts in combination with attractive world market prices have spurred variety adoption and area expansion in Myanmar [13].

Economic surplus model

The economic surplus method is the most widely used approach to quantify the impact of crop improvement research (for recent applications see [10, 31, 33, 37]). Economic surplus refers to the aggregated difference between the consumers' willingness to pay and the production cost for the demanded quantity. This surplus can be conceptualized as the area between an upward sloping supply curve and a downward sloping demand curve up to the point where demand equals supply (the market equilibrium). The introduction of a new technology such as an improved variety, shifts the supply curve down and to the right, thereby expanding the area between the supply and demand curves and creating economic gain.

The method is not without criticism for it is a simplistic way to quantify economic gains and makes strong assumptions about the shape of demand and supply curves, the existence of a market equilibrium, and about the shift in the supply curve as a result of the introduction of a new technology. Yet, the method is parsimonious in its data requirements, which allows its application to developing countries where detailed farm-level panel data are generally unavailable. Furthermore, it is transparent and easy to check and replicate and the assumptions can be tested through sensitivity analysis. The data and analyses are available with this publication. These strengths explain why the economic surplus method has been widely applied to quantify the impact of agricultural technologies (e.g., [1, 2, 10, 21, 25, 33, 38]).

There are several versions of the economic surplus model [6]. Here we selected a large open-economy model because Myanmar exports most of its mungbean output and the price that farmers receive is therefore set in international markets. The market clearing condition is ensured in the model by equating excess supply and excess demand, which is the difference between total production and domestic demand. However, international price-spillover effects could not be estimated for the lack of data on global mungbean production and consumption as the crop is not separately listed in the statistics database of the Food and Agriculture Organization of the United Nations. Thus, welfare effects were quantified for Myanmar only.

Producer benefits are determined by the magnitude of the supply shift, the decline in prices and initial rise in output (see [6] p. 214–216 for model description and [5, 15, 23] for applications). Important assumptions in the analysis are the absence of technology spillover effects on other crops, linear supply and demand functions, a parallel supply shift, a single equilibrium world market price, and uniform market prices all over Myanmar. These assumptions are necessary for lack of data and empirical analysis on these aspects.

The economic gain or total welfare effects (TS) is the sum of two components: the producer surplus (PS), which is the economic gain accruing to producers, and a consumer surplus (CS), which is the economic gain to consumers from increased availability and lower prices. Following Alston et al. [6], the model is specified as:

$$\Delta \mathrm{CS}_t = P_t C_t Z_t (1 - 0.5 Z_t \eta), \tag{1}$$

$$\Delta \mathrm{PS}_t = P_t Q_t (K_t - Z_t)(1 - 0.5 Z_t \varepsilon), \tag{2}$$

$$\Delta \mathrm{TS}_t = \Delta \mathrm{CS}_t + \Delta \mathrm{PS}_t, \tag{3}$$

where P_t is the world market price in year t (USD/t), Q_t is domestic production in year t, C_t is domestic consumption in year t, both expressed in tons, and $Z_t\eta$ is the price effect explained below. The effect of technological change is captured by the supply-shift variable K_t, which is the per-unit and per-period cost reduction due to the new variety:

$$K_t = A_t \left[\left(\Delta Y / Y_t \right) / \varepsilon + \Delta X / P_t \times Y_t \right], \tag{4}$$

where ΔY is the yield gain of the new variety (in t/ha) over the variety it replaced, which is assumed to be constant, Y_t is the average yield in year t, ε is the domestic price elasticity of supply, and ΔX is the change in production cost from technology adoption (USD/ha). A_t is the area planted to an improved crop variety. It is assumed that variety adoption profiles follow bell-shaped curves. The upward part of the curve was estimated using a logistic regression model:

$$A_t = U \Big/ \left(1 + e^{-a-bt} \right), \tag{5}$$

where U is the upper bound on adoption, b is the slope coefficient related to the rate of adoption, and a is the intercept related to the time when adoption begins. Equation (5) can be transformed into the linear form:

$$\ln \left[A_t / (U - A_t) \right] = a + b_t, \tag{6}$$

so that parameters a and b can be estimated using ordinary least squares (OLS) regression given a minimum of three observations for Y_t and assuming a value for U. Increased yields and a possible change in production costs, increase the market supply but exert a downward pressure on the market price, which is captured by Z_t:

$$Z_t = \varepsilon K_t \big/ [\varepsilon + s\eta + (1 - s_t)\eta_{\text{row}}], \quad (7)$$

where η is the domestic price elasticity of demand and η_{row} is the price elasticity in international markets (ROW meaning "rest of the world").

Data

Adoption curves

The adoption curves in Eq. (6) were estimated using unpublished data provided by DoA for the period 2012–2015 and combined with data from Schreinemachers et al. [34]. The first observation was obtained by assuming a 1% adoption rate in the first year of introduction (Table 1). Upper bounds were based on expert estimates. Adoption curves were estimated separately for four popular mungbean varieties that resulted from international agricultural research: Yezin 9, Yezin 11, Yezin 14 and MAS 1. The independent estimation of four adoption curves slightly overestimated the aggregate adoption of these four varieties by 5% in 2016 and the curves were therefore calibrated downward to match the official data and avoid overstating the impact.

Table 1 Summary of parameters and variables used in the analysis

Parameter/variable	Value
Mungbean-planted area in 2016 (million ha)	1.22
Mungbean production (t)	1.09
Mungbean yield (t/ha)	0.89
Mungbean harvest consumed domestically (%)	7.70
Introduction of improved mungbean varieties (year):	
Yezin 9	2000
Yezin 11	2006
Yezin 14	2008
MAS 1	2007
Yield premiums over older varieties (proportion):	
Yezin 9	0.61
Yezin 11	0.15
Yezin 14	0.36
MAS 1	0.34
Cost premium of all improved varieties (USD/ha)	0.00
Price elasticities:	
Domestic supply	0.44
Domestic demand	0.00
International market demand	0.75
Discount rate (% per annum)	5

30-year time series data on area, production, yield, variety adoption and prices included in the online data annex

Area, production and consumption

Data on the planted mungbean area (ha), production (t) and national average yield (t/ha) were taken from official ministry data for the period 2000–2016 (Settlement and Land Records Department, 2016). Domestic consumption was set at 7.7% of production as based on published data for 2017 from the Ministry of Commerce.

Prices

Price series of major exporting countries are good proxies of world market prices [10]. We used "Free On Board" prices from the two major mungbean markets (Yangon and Mandalay) for the period from 2006 to 2017. Export prices were estimated from the export values and quantities exported following JIRCA [20]. Export values and quantities were taken from the Central Statistical Office [13]. Export values in local currency units were converted using a parallel market exchange rates using data from FAOSTAT [16] and deflated with the consumer price index with 2016 as the base year [13].

Price elasticities

There have been no reports of the domestic price elasticity of supply and demand for mungbean in Myanmar. Masters et al. [22] wrote that the results of the economic surplus model are not very sensitive to the value of the demand price elasticity. Since the consumption of mungbean in Myanmar is very low, the domestic demand price elasticity was set to zero, meaning that lower mungbean prices do not increase consumption. We tested the sensitivity of the results for this assumption. Previous studies suggest that the results are more sensitive to the value of the supply price elasticity (e.g., [33]). The mungbean supply elasticity was set to 0.44, which is the average of elasticity values reported in Ali and Abedullah [3], Huijie et al. [19], and Hossain et al. [18]. Finally, the absolute value of the ROW price elasticity of demand was set to 0.75 following Brennan et al. [11].

Crop yield and cost premiums

Performance data for the improved mungbean varieties were taken from on-farm trials conducted by DAR. The average yield of Yezin 9 was taken from three multilocation on-farm trials conducted by DAR in 2000–2003 and showed an average yield of 1.39 t/ha, which was 61% above the yield of the local check, Yezin 5, which was the dominant variety at the time. The average yield of Yezin 14 was taken from three multi-location on-farm trials conducted by DAR in 2008–2010 and showed an average yield of 1.23 t/ha, which was 36% above the yield of the local check, Yezin-11, which was the dominant variety it replaced. The average yield of Yezin 11 and MAS 1 was calculated as the weighted average yields over 2015–2016 from regional Department of Extension (DoE) data. It was determined that the Yezin 11 produced 1.27 t/ha, which was 15% higher than the yield of variety it replaced (Yezin 5), while the yield of MAS 1 was 1.49 t/ha, which was 34% higher than that of the variety it replaced (Yezin 9). We note that the yields recorded in these on-farm trial data were close to the regional weighted average, 1.51 t/ha for Yezin 14 and 1.26 for Yezin 9 in 2015–2016, and close to the national average yield 1.32 t/ha in the same period. This suggests that the yield premiums calculated from on-farm trials were representative for the yield premiums that the average farmer would have obtained. Estimates of variety-specific production costs were unavailable and we relied on local experts from the Food Legumes Section (interviewed during August 2017) who judged that there is no cost difference between old and new mungbean varieties.

Projections for 2017–2030

The projections assume that the estimated bell-shaped adoption curve can be extrapolated until 2030. We took 2030 as the last year of the analysis because the four mungbean varieties are then expected to have very few users and this therefore captures the full benefits of the research investment. Another assumption is that the mungbean area follows a linear trend based on existing values for 2000–2016. All other parameters were kept constant.

Returns on investment

Returns on investment were estimated by comparing economic gains to the cost of developing and scaling the improved varieties. Streams of benefits and costs were converted into net present values by compounding historical values and discounting future values at a real discount rate of 5% per annum as used by nearly all comparable studies (e.g., [2, 10, 31]). We used three standard financial indicators of returns on investment: net present value (NPV) of the benefit and cost cash flow, benefit–cost ratio, and internal rate of return (IRR).

The starting year for the cost calculation was set to 1980, which refers to the start of a breeding collaboration that led to the release of MYMD-resistant varieties, chiefly NM94. The improved varieties studied here are related to this variety, which was created around 1994 and released in 1996, which we assume as the final year of breeding research relevant to this study.

International mungbean breeding research between 1980 and 1996 was entirely funded by core donors to the World Vegetable Center. Following Masters et al. [22], we approximated the investment cost by multiplying total expenditures by the proportion of senior scientists involved in mungbean breeding (including the mungbean breeder as full-time and the pathologist, virologist and nutritionist as part-time). This suggests that about 9.2% of the Center's annual expenditures were allocated to mungbean breeding.

The mungbean breeding program had a focus on Bangladesh, Bhutan, China, India, Nepal, Myanmar, Pakistan, Sri Lanka, and Thailand with India, China, and Thailand being the main recipients of improved mungbean germplasm. In 1980, Myanmar accounted for only 3.3% of the total mungbean area in these nine countries, though this share had increased to 33% in the early 2000s. A conservative assumption would be that one-fifth of the overall mungbean breeding research was directed toward Myanmar and we therefore include one-fifth of the costs.

Scaling efforts were project-based and funded by the UK Department for International Development from 1997 to 2004. These scaling efforts primarily focused on South Asia (India and Pakistan) as Myanmar was largely closed to foreign projects at the time. However, we conservatively assume that one-third of the scaling funds was directed at Myanmar in-line with the country's share in the regions' mungbean area in the early 2000s.

The investment by national partners in Pakistan, Thailand and Myanmar is unknown and impossible to calculate for lack of budget data. World Vegetable Center clearly had a leading role in the research, while partners had a leading role in the scaling. Some of the research and scaling work of the partners was also funded through international agricultural research. For lack of better data, we simply assume that the national partners themselves invested an equal amount of funds in mungbean research and development.

Results

Adoption improved mungbean varieties

The cumulative diffusion curve shows that 46% (556,265 ha) of the mungbean area in 2016 was planted to varieties that resulted from international mungbean research (Fig. 1). This is much lower than the 77% estimated by Schreinemachers et al. [34], but here we use the official data because these are available for several years and could be considered as conservative estimates of the actual adoption. Experts at DAR estimated that an adoption ceiling may be reached in 2017 as other improved varieties are soon to be released and are likely to replace the current varieties. Our study therefore assumes that the adoption of the current four varieties will gradually decline following a bell-shaped curve (see also [24]).

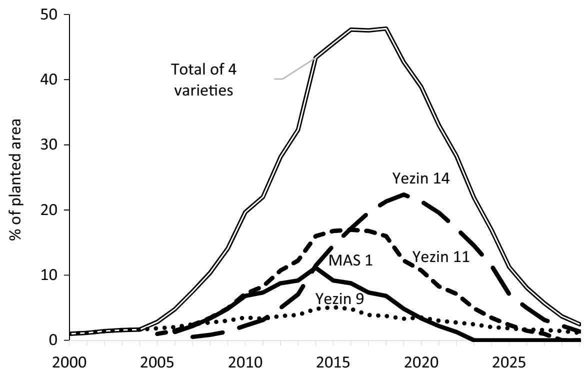

Fig. 1 Adoption profiles of four mungbean varieties in Myanmar, 2000–2030 (projected values for 2017–2030)

Yezin 9 was formally released in 2000 with an adoption ceiling of 5% of the planted area, reached in 2016. Yezin 11 was formally released in 2006, and reached its adoption ceiling of 17% in 2017. MAS 1 was formally released in 2007 and its use has declined after reaching 11% in 2015. Finally, Yezin 14 was released in 2008 and accounted for 15% of the area planted in 2016 and is projected to reach a ceiling of 22% in 2021. Higher adoption of Yezin 11 and Yezin 14 are the result of high yield premiums over other varieties, which is related to their MYMD resistance.

Economic impact and returns on investment

Our results show that mungbean research and development in Myanmar has created total economic gains of USD 1.4 billion from 2000 to 2016 (Table 2). Of these gains, 95% (USD 1.3 billion) accrued to smallholder farmers while only 5% accrued to consumers in Myanmar because most of the production is exported (and thus benefitting consumers outside the country). Extending the analysis up to 2030, when the selected improved varieties are expected to have been largely replaced by other varieties, suggests that the total economic gains will be USD 3.7 billion.

Up to 2016, each of the four varieties contributed similarly (17–33%) to the total economic gains as shown in Fig. 2. However, when extending the period up to 2030 then 49% of the economic gains can be attributed to Yezin 14 because of its high and increasing adoption while the other varieties are expected to lose share.

The cost of mungbean research, extension and promotion in Myanmar from 1980 to 2016 is estimated to be USD 5.0 million, of which USD 2.5 million was invested by the international research center and the other half by the national agricultural system. These costs are small against benefits of USD 1.4 billion. The net present value of the project was USD 1.7 billion and the internal rate of return was 26.7% for the period up to 2016. Each dollar invested into mungbean research and development gave USD 92 in returns. Extending the project period up to 2030, increases this to USD 181 and gives an internal rate of return of 27.5%.

Figure 3 shows the net present value of the economic gains and cost of research, extension and promotion. It illustrates the large time-lag between the start of investment in 1980 and the start of economic benefits, 20 years later in 2000. It also shows the enormous size of the economic benefits as compared to the research and development costs.

Sensitivity analysis

We evaluated the sensitivity of the results to variations in key parameters such as the demand and supply elasticity and discount rates (Table 3). The supply elasticity typically ranges from 0.2 to 1.2 according to Alston et al. [6]. Lower values indicate little expansion potential whereas higher values are used for crops with more potential to

Table 2 Returns to investment of mungbean research and development in Myanmar

Financial indicators	1980–2016	1980–2030
Economic gain (in million USD)	1391.8	3655.3
Consumers (%)	4.7	4.7
Producers (%)	95.3	95.3
Research and development costs (in million USD)	5.0	5.0
Internal rate of return (%)	26.7	27.5
Net present value (in million USD)	1729.4	3431.7
Benefit–cost ratio	91.5	180.6

A 5% discount rate to benefits and costs was applied. In constant 2016 USD values

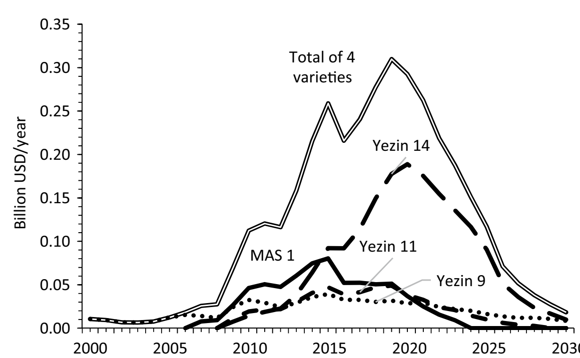

Fig. 2 Annual economic gain of four mungbean varieties in Myanmar, 2000–2030 (projected values for 2017–2030), in constant 2016 USD

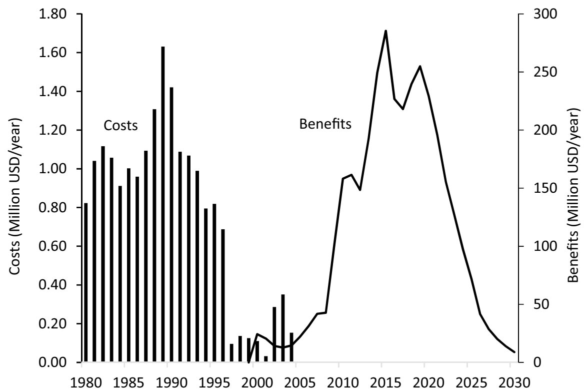

Fig. 3 Net present value (NPV) of costs and benefits of mungbean research and development in Myanmar, 1980–2030. Projected values for 2017–2030. Values for 1980–2016 were compounded to 2016 levels and values for 2017–2030 were discounted to 2016 levels. Includes all four improved varieties studied

Table 3 Sensitivity of results to changes in key parameters

Scenario (baseline values in brackets)	Economic gain (USD billion)	NPV (USD billion)	IRR (%)	Benefit–cost ratio
Baseline	1.4	1.7	26.7	91.5
Supply elasticity (0.44)				
0.22	3.4	4.2	31.5	222.3
0.32	2.1	2.6	28.9	139.1
0.50	1.2	1.5	25.8	77.0
0.70	0.7	0.9	23.3	48.0
Demand elasticity (0.00)				
0.20	1.4	1.7	26.7	92.2
0.40	1.4	1.8	26.7	92.9
0.60	1.4	1.8	26.8	93.5
Discount rate (5.0%)				
3.0%	1.4	1.6	26.7	142.7
10.0%	1.4	2.2	26.7	30.5

All values in 2016 USD

NPV net present value, *IRR* internal rate of return

expand. The fact that mungbean expanded by about 10% annually from 1980 to 2016 suggests that the value should not be too low. The baseline scenario assumed a value of 0.44, which is the average used by previous mungbean impact studies in South Asia. We test the model using lower and upper bounds as used by these previous studies. The results show that the results are sensitive to the supply elasticity. Setting the supply elasticity to 0.22, the lowest value reported, would increase economic gains to USD 3.4 billion, the benefit–cost ratio to 222.3 and the IRR to 31.5%. However, setting the supply elasticity to 0.70, which is the highest value reported, would reduce economic gains to USD 0.7 billion, the benefit–cost ratio to 48.0 and the IRR to 23.3%. In contrast, the results are not sensitive to alternative values for the demand elasticity or discount rate.

Discussion

The economic surplus model is not without criticism for it makes relatively strong assumptions as stated in the "Methods" section. We addressed this by making conservative assumptions for those parameters with a large degree of uncertainty such as the adoption rate of improved varieties. Other assumptions were tested through sensitivity analysis, the results of which suggest an interval for the economic impact estimates. We also have made all data and analyses publicly available for scrutiny. We believe that this careful application of the economic surplus model justifies its use, while noting that there are no real alternatives to this method in a data scarce situation such as mungbean in Myanmar. We also note that economic gain is in itself not a good indicator of changes in food security as it is not a household-level indicator and it is important to take into account several aspects of food security [32].

In terms of results, our study shows that the collaborative work of World Vegetable Center and DAR generated large economic gains in Myanmar, of USD 1.4 billion up to 2016 and returns on investment of 27%. The economic gain is projected to increase to USD 3.7 billion by 2030, which does not account for newer mungbean varieties that are currently being prepared for release. The economic gains are impressive when considering that mungbean only occupies about 6% of the cultivated area in Myanmar and the crop is just 60-70 days in the field, requiring little fertilizer or irrigation.

The total gains may appear high compared to previous impact studies on mungbean for Pakistan and Bangladesh [4, 18], but the mungbean area in Myanmar is more than three times that of Bangladesh and Pakistan combined. Furthermore, these earlier studies were conducted relatively early in the diffusion of MYMD-resistant varieties. For instance, the study of Ali et al. [4] was conducted just 2 years after their release.

The estimated economic gains are conservative and are likely to underestimate the true impact for several reasons. First, the true adoption rates might be higher than what we have used in our analysis. A previous adoption study using expert elicitation methods estimated a combined adoption of 77% for 2016, but this study assumed that this was only 48% as we fitted logistic curves to the official data. Official data rely on government extension staff while our estimates relied on a diverse set of mungbean experts (lead farmers, government staff, traders) and applied a delphi method for creating consensus. We therefore believe that the government data are likely to underestimate the adoption of improved varieties and the impact estimates reported here are likely to underestimate the true impact.

Second, we did not quantify the economic gains for consumers outside Myanmar, particularly in India which is the main importer of mungbean. These additional gains will be large as 92% of the harvest is exported. Third, it is well-known that pulses like mungbean give secondary benefits in term of improved human nutrition and soil fertility improvement, which were not considered in the analysis.

Past accomplishments and projections of future impact do not imply that we can be complacent with the status-quo. Average mungbean yields in Myanmar are low at just 1.3 t/ha and yields are even lower in South Asia. There are problems with seed quality and current varieties do not offer comprehensive resistance to a range of diseases such as powdery mildew, Cercospora leaf spot and MYMD. Also, there is evidence that current sources of MYMD resistance in Myanmar may not be sufficient to withstand other strains/species of the virus [26]. Dry root rot [28], heat stress, salinity and the need for mechanized harvesting are other challenges that require the development of new varieties.

Importantly, the results show that research investments in nutrient-rich crops that are minor in terms of global acreage, provide comparable returns on investment when compared to staple food crops (e.g., [1, 38]). This finding is important in light of the need to diversify food systems to meet contemporary nutrition challenges as diversifying agricultural investments into minor crops will not reduce returns on investment.

Conclusion

International mungbean breeding, involving the World Vegetable Center and national agricultural research and extension systems, has generated tremendous economic impact in Asia. Our study estimates that the impact for Myanmar alone was USD 1.4 billion until 2016 and this will increase to USD 3.7 billion by 2030. However, the time lag between the start of research investment and the start of impact was 20 years. Investment in agricultural research needs to diversify into nutrient-rich crops and this study provides evidence that such diversification will not reduce returns on investments. Key to the success was a culture of germplasm sharing and international collaboration. The varieties that made an impact contained germplasm supplied by the national agricultural research programs of India, Pakistan, Thailand, the Philippines, and perhaps also other countries. This is important to consider as this culture of sharing is currently under threat as countries increasingly try to claim ownership over their genetic resources.

Supplementary information

Supplementary information accompanies this paper at https://doi.org/10.1186/s40066-020-00260-y.

Additional file 1. Sheet 1: Adoption Profiles. Adoption profiles of Yezin 9, 11, 14 and MAS 1. Sheet 2: Impact model. Description of the formulas of the economic surplus model for large open economy with no spillovers. Sheet 3: Parameters. Variables, data and assumptions in the economic surplus estimation of improved mungbean for Myanmar. Sheet 4: Scenarios. Economic gains from different scenarios. Sheet 5: Cost. Data and assumptions in the cost estimation of improved mungbean varieties for Myanmar, 1980–2004. Sheet 6: Financial indicators. Financial indicators results from different scenarios. Sheet 7: Sensitivity. Summary table of economic gains and financial indicators from 10 different scenarios. Sheet 8: Figures. Sheet 9: Tables.

Abbreviations

DAR: Department of Agricultural Research; DoA: Department of Agriculture; DoE: Department of Extension; ha: Hectares; IRR: Internal rate of return; MYMD: Mungbean yellow mosaic disease; NPV: Net present value; t: Tons; USD: United States dollar.

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Authors' contributions

TS and PS designed the study, TS analyzed the data, PS and TS wrote a first draft of the paper. LD, TS and RMN contributed to the design and results interpretation. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article and its Additional file 1.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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