Ex-ante Evaluation of Research and Technology Options for **Grain Legumes and Dryland Cereals in Sub-Saharan Africa and South Asia**

This report is commissioned by ICRISAT to accompany the proposal on
CGIAR Research Program on
Grain Legumes and Dryland Cereals Agri-food Systems

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1. Introduction

A panel of experts reviewing the CGIAR Research Program Proposal on Grain Legumes and Dryland Cereals (GLDC) recommended that the participating centers set research priorities based on rigorous yield gap analyses, ex ante impact analyses and return on investment projections benchmarked against past results. This brief presents the methods and results of an ex ante evaluation of research and technology options for grain legumes (cowpea, chickpea, lentil, groundnut, pigeonpea and soybean) and dryland cereals (sorghum, pearl millet and finger millet) in the drylands of Sub-Saharan Africa and South Asia. The projected impacts of the different lines of research are measured in terms of the present value of net economic benefits (NPV), internal rates of return (IRR), and benefit-cost ratios (BCR). In an effort to guide priority setting, the research and technology options are ranked by mega-environment (ME), based on the BCR as a measure of the net economic benefits per unit of investment.

2. Data and Methods

Data sources

The priority assessment involved a sequential process of conceptualization, operationalization and quantification. First, the eight major mega-environments were defined for which priority crops and lines of research should be identified: (1) semi-arid West & Central Africa; (2) dry sub-humid West & Central Africa; (3) semi-arid East Africa; (4) dry sub-humid East Africa; (5) semi-arid Southern Africa; (6) dry sub-humid Southern Africa; (7) semi-arid South Asia; and (8) dry sub-humid South Asia. Secondly, crop-specific expert groups were established at a GLDC/stakeholder workshop to provide information for yield gap and constraints analyses for each crop as well as for the overall ex ante impact assessment using a structured questionnaire prepared for this purpose. The information includes yield gaps based on actual average yields and potential attainable yields under rainfed conditions; major biotic and abiotic constraints and other factors responsible for the yield gaps and their relative importance; and promising lines of research and resulting technologies with potential to bridge the yield gaps. Estimates of a range of technology-related parameters elicited from the expert groups were reviewed and adjusted based on information from past published and unpublished work. The parameters include the: (1) probability of research success; (2) research lag in terms of the number of years it would take to make the technologies available to farmers; (3) additional adoption costs as a proportion of the cost of production per ha; (4) adoption lag; (5) staff costs in terms of full time equivalent scientist years; and (6) estimated annual budget required to develop the technology. Dissemination costs were estimated separately for new varieties (US$50/ha of additional area under new varieties) and other knowledge-intensive technologies such as integrated soil fertility management, crop and water management ($75/ha of additional area under improved crop, soil fertility, or water management).

Methods

The economic surplus model (Alston et al. 1995) was used to derive summary measures of the potential impacts of GLDC research and technology options under certain reasonable assumptions that research starts in 2018 and benefits accrue from the beginning of the adoption of improved technologies. The benefits were measured based on a parallel downward shift in the (linear) supply curve following research. The annual flows of gross economic benefits from research were estimated for each of the 82 GLDC technology options and 8 mega-environments identified. The key parameters that determine the magnitude of the economic benefits are: (1) the expected technology adoption in terms of area under improved technologies; (2) expected yield gains (or avoided losses) following adoption; and (3) pre-research levels of production and prices. Specifically, the economic surplus empirical model for an open economy was used to calculate the economic benefits for each technology and mega-environment from a downward shift in the supply curve. In an open economy, economic surplus measures can be derived using formulas presented in Alston et al. (1995)—i.e., change in economic Surplus (ΔES) = $P_0Q_0K_t\,(1{+}0.5K_t\varepsilon)$; where K_t is the supply shift representing cost reduction per ton of output as a proportion of product price (P); P_0 represents pre-research world price (US$/ton); Q_0 is the pre-research level of production; and ε is the price elasticity of supply. The research-induced supply shift parameter, K, is the singlemost important parameter influencing total economic surplus results from unit cost reductions and was derived as $K_t=[\Delta Y/\varepsilon-\Delta C/(1+\Delta Y)]pA_t$ where ΔY is the average proportional yield increase per hectare, given that research is successful and the resulting innovation fully adopted; ΔC is the expected proportional increase or decrease in the variable production costs required to achieve the expected yield increase or avoided yield loss; p is the probability of research success; A_t is the expected rate of adoption of the technology at time t; and ε is the price elasticity of supply.

Annual supply shifts were then projected based on the projected adoption profile for improved technologies (A_t) for the period 2018 to 2042 for research starting in 2018. Adoption (A_t) is assumed to follow the logistic diffusion curve starting with less than 1% of the area placed under improved technologies in the first year of adoption. Established procedures were followed to estimate the research benefits using alternative measures. First, the changes in economic surplus (ΔES) and the research and extension costs (C_t) are discounted at a real discount rate, r, of 10% per annum to derive the net present values (NPVs). Second, the internal rates of return (IRRs) were calculated as the discount rate that equates the aggregate net present value (NPV) to zero. Finally, the benefit-cost ratios (BCR) were also calculated as the ratio of the present values of aggregate benefits to the present values of research and extension costs. Given that IRR estimates have implausible economic implications when interpreted as a conventional compounding interest rate, it is argued that ranking of agricultural research investments should be done using either the marginal internal rate of return or the BCR (Rao et al. 2012).

3. Results of the ex-ante impact assessment using the economic surplus model

The summary measures of the ex-ante economic benefits and the implied rankings of GLDC research and technology options for each mega-environment are presented in Tables 1-8. These are ordinal rankings of different lines of research based on the BCRs as measures of economic benefits per unit of investment to inform resource allocation decisions at a time of increasingly tight budgets. This is justified when the objective of research investment policy is to maximize economic benefits from agricultural research. As research objectives include both economic efficiency as well as poverty reduction, future priority setting efforts should account for potential poverty reduction effects of alternative lines of research and the resulting technologies. While this ranking is most appropriate for setting thematic research priorities, strategic commodity priorities are also implied by the projected benefits per unit of investment in the specific lines of research and resulting technologies. While the different lines of research are highly complementary options, the assumption underlying the ex-ante analysis is that only one technology option would be developed and adopted at a time. As such, the estimated benefits should not be aggregated across technologies for each crop.

The results of the ex-ante impact assessment of technology options show considerable potential for impact of investments in GLDC research. A number of research and technology options across mega-environments and crops have great potential to generate positive economic impacts, indicating the high profitability of investments in GLDC research to address a whole range of production and related constraints. The research and technology options with the greatest potential impacts across crops are:

- Short-duration, drought-tolerant varieties of cowpea, groundnut, lentil, pearl millet, pigeonpea, sorghum and soybean coupled with soil and water conservation practices;
- Disease-resistant varieties of chickpea, groundnut, lentil, millet and soybean (rosette, Fusarium wilt, leaf spot/root rot, downy mildew, blast, smut, blight, Botrytis gray mold and bud necrosis);

- Insect-resistant varieties of cowpea and pigeonpea (aphids, thrips, pod sucking bugs/borers, maruca and pod fly) and integrated pest management practices including biological control;
- Integrated crop and soil fertility management practices including P-use efficiency;
- Parasitic weeds-resistant varieties of cowpea and sorghum (Striga and Alectra);
- Herbicide-tolerant varieties of chickpea and lentil; and
- Optimum plant population in groundnut and the use of inoculants and Phosphorous fertilizer in soybean.

Table 1. Summary measures of potential economic benefits and rankings of research/technology options in semi-arid West & Central Africa.

Crops	Research/technology options	NPV (US$ million)	IRR (%)	BCR	Ranking
Sorghum	Early-maturing varieties and hybrids with tolerance to drought	1555	130	23	1
Groundnut	Drought-tolerant/resistant variety and short-duration (early-maturing) variety	173	49	21	2
Cowpea	Drought-tolerant varieties and integrated crop management	360	59	16	3
Cowpea	Insect- (aphid, thrips, pod sucking bug, maruca) resistant lines and integrated pest management including biological control	356	57	16	4
Pearl millet	Genetically diverse dual-purpose hybrid parents/cultivars with high and stable yields with disease resistance (downy mildew and blast)	450	64	14	5
Groundnut	Pre and postharvest aflatoxin management practices including Good Agricultural Practices (GAP)	234	111	14	6
Pearl millet	Early-maturing, drought-tolerant hybrids which can give stable yields under severe drought conditions	422	55	13	7
Cowpea	Low P-tolerant varieties and integrated crop management	220	53	12	8
Sorghum	Striga-resistant varieties and hybrids	557	98	9	9
Groundnut	Rosette-resistant variety	52	40	8	10
Groundnut	Moderately-resistant variety (for short-duration variety) and highly- resistant variety (for medium- and long-duration varieties) to early and late leaf spot	66	42	7	11
Cowpea	Striga-resistant varieties and integrated crop management	124	50	6	12
Cowpea	Disease-resistant varieties and integrated crop management	123	44	6	13
Groundnut	Soil fertility management for P and other nutrients (N, Ca) including chemical/organic fertilizers application	91	79	6	14
Pearl millet	Biological control of millet head miner and resistant hybrid parents	253	50	6	15
Sorghum	Stem borer/midge-tolerant cultivars	289	76	5	16
Pearl millet	Integrated soil fertility management and identifying genotypes for low P tolerance	112	43	3	17
Groundnut	Low P-tolerant/efficient variety	15	35	3	18
Sorghum	Cultivars adapted to low soil fertility/and with nutrient-use efficiency	50	35	2	19
Pearl millet	OPVs with host plant resistance to *Striga hermonthica*	31	28	2	20

Table 2. Summary measures of potential economic benefits and rankings of research/technology options in dry sub-humid West & Central Africa.					
Crops	**Research/technology options**	**NPV (US$ million)**	**IRR (%)**	**BCR**	**Ranking**
Groundnut	Drought-tolerant/resistant variety and short-duration (early- maturing) variety	129	45	16	1
Cowpea	Insect- (aphid, thrips, pod sucking bug, maruca) resistant lines and integrated pest management including biological control	120	46	16	2
Soybean	Drought-tolerant varieties and crop management and water conservation practices	58	53	16	3
Cowpea	Drought-tolerant varieties and integrated crop management	108	46	15	4
Soybean	Disease-resistant varieties and integrated pest management and crop management practices	43	58	14	5
Groundnut	Pre and postharvest aflatoxin management practices including Good Agricultural Practices (GAP)	234	111	14	6
Soybean	Use of inoculant and fertilizers especially Phosphorus	43	63	12	7
Cowpea	Low P-tolerant varieties and integrated crop management	77	42	12	8
Groundnut	Increased plant population	140	89	11	9
Cowpea	Striga-resistant varieties and integrated crop management	60	44	10	10
Sorghum	Medium- to late-maturing anthracnose-resistant cultivars	307	88	10	11
Cowpea	Disease-resistant varieties and integrated crop management	59	38	8	12
Groundnut	Rosette-resistant variety	52	40	8	13
Sorghum	Striga-resistant varieties and hybrids	227	75	7	14
Groundnut	Moderately-resistant variety (for short-duration variety) and highly-resistant variety (for medium- and long-duration varieties) to early and late leaf spot	43	38	7	15
Groundnuts	Soil fertility management for P and other nutrients (N, Ca) including chemical/organic fertilizers application	91	79	6	16
Sorghum	Head bugs- and grain mold-tolerant cultivars	105	49	4	17
Sorghum	Cultivars adapted to low soil fertility/and with nutrient-use efficiency	65	38	4	18
Sorghum	Stem borer/midge-tolerant cultivars	36	27	2	19

Table 3. Summary measures of potential economic benefits and rankings of research/technology options in semi-arid East Africa.					
Crops	**Research/technology options**	**NPV (US$ million)**	**IRR (%)**	**B/C Ratio**	**Ranking**
Sorghum	Early-maturing varieties and hybrids with tolerance to drought	364	98	15	1
Pigeonpea	Fusarium wilt- and Cercospora leaf spot-resistant varieties	33	62	15	2
Chickpea	Ascochyta blight-resistant varieties	17	50	12	3
Pigeonpea	Photo- and thermo-insensitive varieties	29	70	12	4
Groundnut	Drought-tolerant/resistant variety and short-duration (early-maturing) variety	41	38	10	5
Chickpea	Fusarium wilt- and root rots-resistant varieties	18	49	10	6
Finger millet	Validate and promote water management options; fertilizer regimes	20	59	9	7
Pigeonpea	Cleisto varieties and maintenance breeding to reduce varietal degeneration due to out crossing	20	52	9	8
Pigeonpea	Drought-tolerant varieties	17	55	9	9
Sorghum	Stem borer/midge-tolerant cultivars	264	87	8	10
Sorghum	Striga-resistant varieties and hybrids	264	83	8	11
Pigeonpea	Intercropping compatible-varieties and integrated crop management options	22	55	8	12
Groundnut	Pre and postharvest aflatoxin management practices including Good Agricultural Practices (GAP)	19	53	7	14
Chickpea	Drought-tolerant varieties	13	40	6	15
Pearl millet	Varieties and hybrid parents with good establishment and respond well to drought especially terminal drought	35	38	6	16
Pearl millet	Validate and promote water management options; fertilizer regimes	56	71	5	17
Pigeonpea	Varieties tolerant to pod borers, pod fly, pod bugs and integrated pest management	10	39	5	18
Sorghum	Integrated crop management options for soil fertility, water management, Striga, intercropping.	202	91	5	19
Finger millet	Varieties and hybrid parents with good establishment and that respond well to drought, especially terminal drought	8	26	5	20
Pearl millet	Early-maturing, drought-tolerant hybrids which can give stable yields under severe drought conditions	29	32	5	21
Cowpea	Drought-tolerant varieties and integrated crop management	7	25	5	22
Cowpea	Insect- (aphid, thrips, pod sucking bug, maruca) resistant lines and integrated crop management	7	24	4	23
Groundnut	Rosette-resistant variety	16	31	4	24
Pearl millet	Genetically diverse dual-purpose hybrid parents/cultivars with high and stable yields with disease resistance (downy mildew and blast)	19	32	4	25
Finger millet	Early-maturing, drought-tolerant OPVs and hybrids which can give stable yields under severe drought conditions	6	21	3	26
Groundnut	Soil fertility management for P and other nutrients (N, Ca) including chemical/organic fertilizers application	7	35	3	27
Finger millet	Downy mildew- and smut-resistant dual-purpose OPVs and hybrid parents	4	21	3	28

Groundnut	Moderately-resistant variety (for short-duration variety) and highly-resistant variety (for medium- and long-duration varieties) to early and late leaf spot	10	25	3	29
Cowpea	Low P-tolerant varieties and integrated crop management	4	21	3	30
Cowpea	Striga-resistant varieties and integrated crop management	3	22	3	31
Chickpea	Waterlogging-tolerant varieties and management practices	3	23	3	32
Finger millet	OPVs with host plant resistance to *Striga hermonthica*	3	18	2	33
Lentil	Drought-tolerant varieties	1	18	2	34
Cowpea	Disease-resistant varieties and integrated crop management	2	16	2	35
Groundnut	Low P-tolerant/efficient variety	3	22	2	36
Lentil	Weed management	0.3	13	1.2	37
Lentil	Rust-resistant varieties	0.3	12	1.2	38
Lentil	Ascochyta blight-resistant varieties	0.3	12	1.2	39

Table 4. Summary measures of potential economic benefits and rankings of research/technology options in dry sub-humid East Africa.

Crops	Research/technology options	NPV (US$ million)	IRR (%)	BCR	Ranking
Sorghum	Early-maturing varieties and hybrids with tolerance to drought	468	129	28	1
Sorghum	Varieties and hybrids with resistance to Striga	200	88	13	2
Sorghum	Medium- to late-maturing anthracnose-resistant cultivars	200	83	13	3
Pigeonpea	Photo- and thermo-insensitive varieties	28	54	12	4
Pigeonpea	Cleisto varieties and maintenance breeding to reduce varietal degeneration due to outcrossing	24	57	12	5
Pigeonpea	Varieties resistant to Fusarium wilt and Cercospora leaf spot	21	64	11	6
Pigeonpea	Drought-tolerant varieties	21	59	11	7
Pigeonpea	Varieties tolerant to warm temperatures	18	66	10	8
Pigeonpea	Weed control	27	89	10	9
Pigeonpea	Intercropping-compatible varieties and integrated crop management options	27	57	10	10
Sorghum	Integrated crop management options for soil fertility, water management, Striga, intercropping	158	113	9	11
Soybean	Disease-resistant varieties and integrated pest management and crop management practices	10	36	9	12
Groundnut	Pre and postharvest aflatoxin management practices including Good Agricultural Practices (GAP)	32	62	8	13
Cowpea	Drought-tolerant varieties and integrated crop management	14	31	8	14
Soybean	Integrated soil fertility management	6	36	7	15
Cowpea	Lines resistant to insects (aphid, thrips, pod sucking bug, maruca) and integrated pest management including biological control	15	29	7	16
Groundnut	Drought-tolerant/resistant variety and short-duration (early-maturing) variety	20	32	7	17
Pigeonpea	Varieties tolerant to pod borers, pod fly, pod bugs and integrated pest management	12	43	7	18
Cowpea	Alectra-resistant varieties and integrated crop management	6	27	5	19

Cowpea	Low P-tolerant varieties and integrated crop management	6	24	4	20
Groundnut	Rosette-resistant variety	10	28	4	21
Cowpea	Disease-resistant varieties and integrated crop management	5	21	3	22
Groundnut	Moderately-resistant (for short-duration variety) and highly-resistant variety (for medium- and long-duration varieties) to early and late leaf spot	6	22	3	23

Table 5. Summary measures of potential economic benefits and rankings of research/technology options in semi-arid Southern Africa.

Crops	Research/technology options	NPV (US$ million)	IRR (%)	BCR	Ranking
Pigeonpea	Varieties resistant to Fusarium wilt and Cercospora leaf spot	7	35	8	1
Pigeonpea	Drought-tolerant varieties	3	37	7	2
Cowpea	Drought-tolerant varieties and integrated crop management	11	29	7	3
Cowpea	Lines resistant to insects (aphid, thrips, pod sucking bug, maruca) and integrated pest management including biological control	12	28	6	4
Pigeonpea	Intercropping-compatible varieties and integrated crop management options	4	36	6	5
Pigeonpea	Cleisto varieties and maintenance breeding to reduce varietal degeneration due to outcrossing	4	32	6	6
Sorghum	Early-maturing varieties and hybrids with tolerance to drought	19	38	5	7
Cowpea	Low P-tolerant varieties and integrated crop management	6	24	4	8
Sorghum	Varieties and hybrids with resistance to Striga	14	36	4	9
Sorghum	Medium- to late-maturing anthracnose-resistant cultivars	14	34	4	10
Cowpea	Alectra-resistant varieties and integrated crop management	4	24	4	11
Sorghum	Integrated crop management options for soil fertility, water management, Striga, intercropping	14	41	3	12
Cowpea	Disease-resistant varieties and integrated crop management	5	21	3	13
Pigeonpea	Varieties tolerant to pod borers, pod fly, pod bugs and integrated pest management	1	20	2	14
Pigeonpea	Photo- and thermo-insensitive varieties	1	17	2	15

Table 6. Summary measures of potential economic benefits and rankings of research/technology options in dry sub-humid Southern Africa.					
Crops	**Research/technology options**	**NPV (US$ million)**	**IRR (%)**	**BCR**	**Ranking**
Groundnuts	Rosette-resistant variety	49	40	14	1
Sorghum	Early-maturing varieties and hybrids with tolerance to drought	45	68	12	2
Soybean	Use of inoculant and fertilizers, especially Phosphorus	29	63	10	3
Groundnut	Drought-tolerant/resistant variety and short-duration (early-maturing) variety	28	35	8	4
Soybean	Disease-resistant varieties and integrated pest management and crop management practices	15	36	8	5
Soybean	Drought-tolerant varieties and crop management and water conservation practices	21	33	8	6
Soybean	Use of good quality seed, appropriate seeding rate and row spacing	21	56	7	7
Groundnut	Soil fertility management for P and other nutrients (N, Ca) including chemical/organic fertilizers application	35	63	6	8
Soybean	Establish optimum planting window and awareness creation	20	53	6	9
Soybean	Matching varieties that fit the growing period	18	52	6	10
Groundnut	Pre and postharvest aflatoxin management practices including Good Agricultural Practices (GAP)	28	54	5	11
Sorghum	Medium- to late-maturing anthracnose-resistant cultivars	16	38	5	12
Cowpea	Lines resistant to insects (aphid, thrip, pod sucking bug, maruca) and integrated crop management	6	22	4	13
Sorghum	Integrated crop management options for soil fertility, water management, Striga, intercropping	20	47	4	14
Sorghum	Varieties and hybrids with resistance to Striga	15	37	4	15
Cowpea	Drought-tolerant varieties and integrated crop management	6	24	4	16
Cowpea	Low P-tolerant varieties and integrated crop management	2	18	3	17
Cowpea	Striga and Alectra-resistant varieties and integrated crop management	2	19	2	18
Cowpea	Disease-resistant varieties and integrated crop management	3	18	2	19
Groundnut	Moderately-resistant variety (for short-duration variety) and highly-resistant variety (for medium- and long-duration varieties) to early and late leaf spot	4	19	2	20
Groundnut	Low P-tolerant/efficient variety	0.04	10	1	21
Soybean	Breeding for resistance to parasitic weeds and integrated weed management	0.02	10	1	22

Table 7. Summary measures of potential economic benefits and rankings of research/technology options in semi-arid South Asia.					
Crops	**Research/technology options**	**NPV (US$ million)**	**IRR (%)**	**BCR**	**Ranking**
Chickpea	Varieties resistant to Fusarium wilt and root rots	499	104	17	1
Groundnut	Varieties resistant to diseases (foliar fungal, bud necrosis, soil borne)	66	39	8	2
Pigeonpea	Varieties resistant to Fusarium wilt and Cercospora leaf spot	258	91	16	3
Lentil	Drought-tolerant varieties	80	62	15	4
Groundnut	Integrated crop management practices	72	58	7	5
Groundnut	Soil fertility management for P and other nutrients (N, Ca) including chemical/organic fertilizers application	279	109	16	6
Lentil	Varieties resistant to wilt and root rots and integrated pest management	68	66	12	7
Chickpea	Herbicide-tolerant varieties to control weeds	334	91	12	8
Chickpea	Drought-tolerant varieties	334	91	11	9
Pearl millet	Genetically diverse dual-purpose hybrid parents/cultivars with high and stable yields with disease resistance (downy mildew and blast)	310	54	10	10
Groundnut	Pre and postharvest aflatoxin management practices including Good Agricultural Practices (GAP)	105	56	10	11
Pearl millet	Breeding for early-maturing, drought-tolerant hybrids which can give stable yields under severe drought conditions	180	57	7	12
Finger millet	Breeding for downy mildew- and smut-resistant dual-purpose OPVs and hybrid parents	21	40	6	13
Pearl millet	Integrated crop management	334	115	6	14
Finger millet	Integrated crop management	37	58	6	15
Lentil	Herbicide-tolerant varieties to control weeds	16	37	6	16
Sorghum	Early-maturing varieties and hybrids with tolerance to drought	74	65	5	17
Pigeonpea	Varieties tolerant to pod borers, pod fly, pod bugs and integrated pest management	65	58	5	18
Finger millet	Genetically diverse dual-purpose hybrid parents/cultivars with high and stable yields	16	28	4	19
Chickpea	Pod borer-tolerant varieties and integrated pest management	61	38	4	20
Pigeonpea	Sterility mosaic disease-resistant varieties	57	54	4	21
Finger millet	Breeding for early-maturing, drought-tolerant OPVs and hybrids which can give stable yields under severe drought conditions	11	30	4	22
Groundnut	Low P-tolerant/efficient variety	1	17	1	23
Lentil	Heat-tolerant varieties	7	26	3	24
Sorghum	Genetic base diversification	235	63	4	25
Sorghum	Cultivars tolerant to head bugs and grain mold	259	64	4	26
Pigeonpea	Intercropping compatible-varieties and integrated crop management options	35	35	2	27
Sorghum	Shoot fly-resistant cultivars	198	54	4	28
Chickpea	Heat-tolerant varieties	35	30	2	29
Pigeonpea	Drought-tolerant varieties	16	25	2	30
Sorghum	Charcoal rot-resistant cultivars	45	26	2	31

Table 8. Summary measures of potential economic benefits and rankings of research/technology options in dry sub-humid South Asia.					
Crops	**Research/technology options**	**NPV (US$ million)**	**IRR (%)**	**BCR**	**Ranking**
Chickpea	Varieties resistant to Fusarium wilt and root rots	363	90	12	1
Chickpea	Botrytis gray mold-resistant varieties	273	82	9	2
Lentil	Herbicide-tolerant varieties to control weeds	34	48	8	3
Lentil	Drought-tolerant varieties	39	46	5	4
Lentil	Stemphylium blight-resistant varieties and integrated pest management	38	49	5	5
Chickpea	Pod borer-tolerant varieties and integrated pest management	87	41	5	6
Lentil	Heat-tolerant varieties	13	31	3	7
Chickpea	Drought-tolerant varieties	1.3	11	0.02	8

4. Gaps and plans for future work

While the projected benefits can serve as indicative measures of the prospects of a whole range of GLDC research and technology options, it is worth noting the following gaps and the plans for the future.

- A stakeholder consultation workshop is required to share and discuss the results not only with the GLDC researchers but also with other stakeholders, especially the national and regional organizations, to seek further inputs and refinements based on a shared understanding and realistic assessment of the prospects for development and dissemination of the different technologies across regions and countries.
- The ex-ante analysis only estimates the economic gains from GLDC research investments. Further analysis is required to assess the distribution of the economic gains from research and to estimate the number of poor people who will be lifted out of poverty. Although introducing a poverty dimension may not lead to a significant shift in priorities (Alene et al. 2009), such equity criteria can be given greater weights than the economic efficiency criteria in ranking alternative lines of research with a view to sharpening the focus of GLDC for achieving greater impacts on poverty reduction in the target regions.
- For quality improvement research options such as aflatoxin-free groundnut varieties or varieties with desired market attributes that generate economic benefits mainly through demand shifts rather than supply shifts, further efforts should be made to refine the models to fully account for economic gains due to shifts in the demand function and the resulting price changes.
- For research options such as breeding for nutritional quality (e.g., iron, zinc, etc.) that generate nutritional and health benefits, more appropriate models such as Disability Adjusted Life Years should be developed and applied.
- While scientists are in a better position to specify likely research lags, probabilities of success, staff requirements, and expected yield improvements from their own research, there might be legitimate questions about the reliability of information generated through this process and the inherent biases. Expert estimates can be too subjective and the resulting benefit estimates biased especially if there are no opportunities for peer review and re-estimation to arrive at consensus estimates. As there was no such peer review of expert estimates used in the analysis mainly due to time constraints, the results and the priority rankings should be updated/refined through a continuous and dynamic priority assessment process.

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