Photo 1: *Healthy 3R-gene potatoes (A) and devastated non-biotech potatoes (B) by late blight disease in Musanze in Rwanda.*

Building Resilience in Rwanda's Potato Sector with Late Blight-Resistant Varieties

Key messages

- Potato is an important food security and income crop for smallholders in Rwanda, but late blight (LB) remains one of the most devastating diseases, causing yield losses of 13–60%, and up to 75% if uncontrolled.
- Farmers rely mainly on fungicides to manage LB, yet application practices are challenging across agroecological zones, and conventional breeding has not provided durable resistance.
- The 3R-gene potato varieties (Shangi and Victoria) were developed by transferring three LB resistance genes from wild relatives into farmer-preferred varieties to provide complete and durable resistance.
- Under the most likely adoption scenario, 3R-gene Shangi is projected to generate annual net benefits of RWF 4,514 million (US$ 3.64 million), and Victoria RWF 2,020 million (US$ 1.63 million), with farmers capturing most of the gains.
- As an alternative way of expressing these welfare gains, baseline estimates suggest that 3R-gene Shangi could lift about 909 people out of poverty each year (27,269 over its lifetime), and 3R-gene Victoria about 407 per year (12,201 over its lifetime).
- Sensitivity analysis shows that net benefits remain positive even under less favorable assumptions (lower adoption, halved yield gains, higher discount rates, or delayed release), though gains are reduced—highlighting the importance of timely release and strong adoption.
- Policy and investment priorities include a timely and inclusive rollout of 3R-gene varieties, strengthened seed systems, clear risk communication, and ex post evaluations to capture broader health, environmental, and economy-wide impacts.

1. The challenge: late blight losses and limits of current control

Potatoes play a dual role in Rwanda's food system: they support food and nutrition security and provide cash income for smallholder farmers. Potato consumption per capita is still relatively low but is rising with population growth and urbanization. Potato production is concentrated in eight districts, which account for around 82% of total national production, and the crop ranks as the fifth most important in terms of production and consumption, after bananas, cassava, sweet potatoes, and plantains.

Late blight (LB), caused by *Phytophthora infestans,* is a major constraint in these high-altitude production areas. It is the second most prevalent potato disease after bacterial wilt, but is considered the most devastating, with reported yield losses of 13–60%, and up to 75% when no control measures are taken. LB thrives under conditions that are common in Rwanda's potato zones—regular rainfall around 145.5 mm/month, temperatures of 15–20°C, and relative humidity close to 90% through the growing season. It attacks leaves and stems during the vegetative stage, causing foliar lesions and heavy yield reductions.

The dominant response has been fungicide application, timed to canopy development and disease risk. However, recommended spraying practices face several challenges in different agroecological zones, and repeated use of fungicides is costly and logistically demanding for smallholders. Conventional breeding has sought to improve host resistance using genes from wild species, but single R genes have often been rapidly overcome by new pathogen strains. This has left farmers exposed to recurrent disease risk, high control costs, and unstable yields.

2. The solution: 3R-gene Shangi and Victoria for durable resistance

Investment in biotechnology has led to the development of genetically engineered (GE) potato varieties that stack three late blight resistance genes (3R-gene) from wild potato relatives into locally preferred varieties. The 3R-gene Shangi and 3R-gene Victoria were developed by the International Potato Center (CIP) and partners, targeting complete and durable resistance to LB.

By combining three R genes, these varieties are designed to offer more durable resistance than cultivars carrying a single resistance gene, which P. *infestans* has historically overcome. The 3R-gene approach aims to protect yields in high-pressure environments while maintaining the agronomic and culinary traits that farmers and consumers value in Shangi and Victoria.

An ex ante economic assessment is needed to understand the potential benefits of these varieties before release, inform country-specific regulatory decisions, and support evidence-based policy. The Rwanda study uses such an assessment to quantify expected welfare gains and poverty impacts from adopting 3R-gene Shangi and Victoria across major potato agroecological zones.

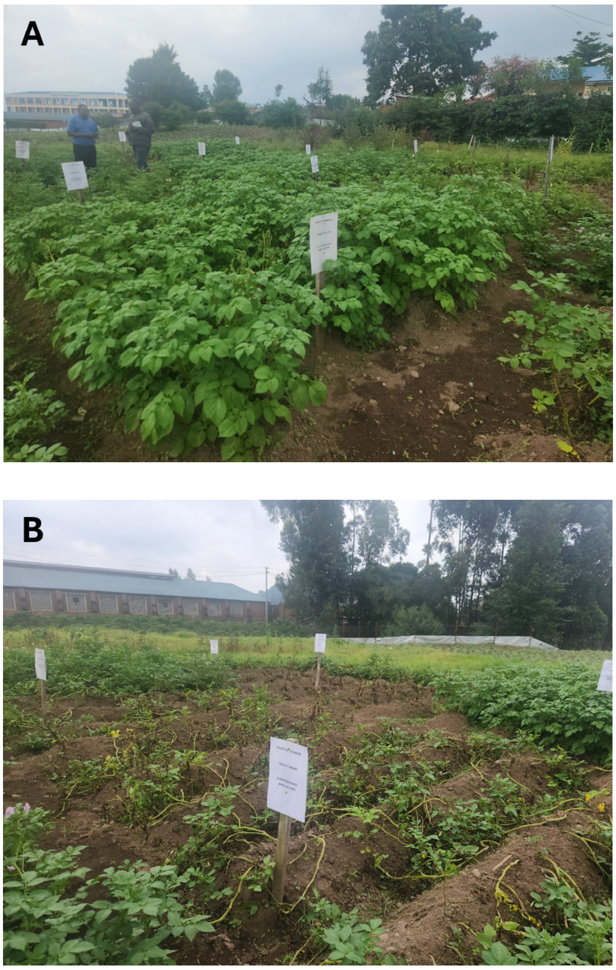

Figure 1: Healthy 3R-gene potatoes (A) and devastated non-biotech potatoes (B) by late blight disease in Musanze in Rwanda.

3. Economic and social impact assessment

The results are based on the economic surplus model (ESM) implemented in DREAMpy, using data and assumptions described in the study. They include baseline projections, sensitivity to key parameters, and poverty impacts as an alternative way of expressing the welfare gains.

Incremental economic returns and distribution

The ESM confirms substantial benefits from the adoption of 3R-gene potato varieties in Rwanda. Over a 30-year simulation period (3 years of R&D plus 27 years of release), the total present value of net benefits is:

- RWF 135,417 million (US$ 109 million) for 3R-gene Shangi, and
- RWF 60,589 million (US$ 49 million) for 3R-gene Victoria.

On an annual basis, the estimated average net social welfare gains are:

- Shangi: RWF 4,514 million (US$ 3.64 million)
- Victoria: RWF 2,020 million (US$ 1.63 million)

The distribution between farmers and consumers is shown in Table 10 of the study, and summarized below as average annual present values:

- 3R-gene Shangi
  - Δ Farmer surplus: RWF 3,155 million (US$ 2.546 million)
  - Δ Consumer surplus: RWF 1,368 million (US$ 1.104 million)
- 3R-gene Victoria
  - Δ Farmer surplus: RWF 1,425 million (US$ 1.150 million)
  - Δ Consumer surplus: RWF 604 million (US$ 0.487 million)

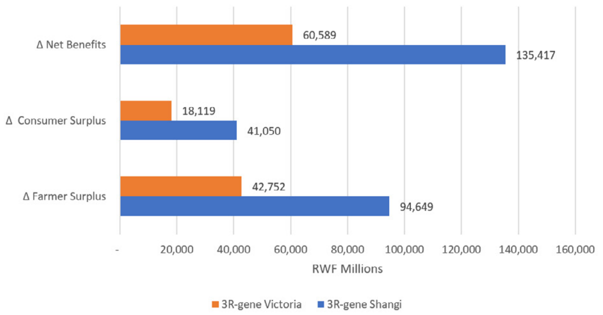

Figure 2. Relative economic performance of Shangi and Victoria over a 30-year period (present value, RWF million)

Farmers are the primary beneficiaries, especially for Shangi, with consumers also gaining through improved availability and price effects.

Regionally, the distribution of benefits varies with adoption rates, potato area, and expected yield and cost changes. For example, average annual net benefits for Shangi are highest in the Buberuka Highlands (RWF 2,846 million) and Zaire–Nile Ridge (RWF 841 million), while the Volcanic Cones and High Plains show a small negative farmer surplus (RWF -24 million) but a large consumer surplus (RWF 856 million), resulting in a positive net benefit (RWF 827 million). Victoria also generates positive net benefits across all zones, with the largest gains in the Volcanic Cones and High Plains.

Poverty impacts as an alternative metric

As an alternative way of presenting the welfare gains, the study translates economic surplus estimates into potential poverty impacts, following a well-established method. Under the baseline scenario:

- 3R-gene Shangi is projected to lift about 909 people out of poverty per year, or 27,269 individuals over its expected lifetime.
- 3R-gene Victoria is projected to lift about 407 people per year, or 12,201 individuals over its lifetime.

Across scenarios, poverty reduction remains positive. Under maximum adoption rates, the number of poor individuals escaping poverty could reach 62,361 for Shangi and 33,051 for Victoria. Under minimum adoption rates, the corresponding figures are 10,662 and 6,635, respectively. Even under more conservative assumptions, the estimated poverty effects remain meaningful.

The cost of delay and other adoption scenarios

Because ex ante assessments rely on assumptions, the study examines how sensitive the results are to changes in adoption ceilings, yield benefits, research and development costs, and discount rates.

- **Adoption rates:** Net benefits are highly sensitive to adoption. Compared with baseline, net benefits can decline by up to 61% (Shangi) and 46% (Victoria) under minimum adoption estimates. Under maximum adoption rates, net benefits increase by up to 129% for Shangi and 171% for Victoria.
- **Discount rate:** Using a higher discount rate of 13%, aligned with Rwanda's Economic Opportunity Cost of Capital (EOCK), reduces the present value of net benefits by 54% for Shangi and 57% for Victoria compared with the baseline (which uses a 6% rate). Even then, net benefits remain positive.
- **Reduced yield benefits:** If expected yield gains are cut by half, net benefits decline by about 46.5% for Shangi and 47.3% for Victoria but remain clearly positive.
- **Delayed release:** A five-year delay in releasing the 3R-gene varieties reduces net benefits by 28.7% (Shangi) and 30.3% (Victoria).
- **Higher R&D costs:** Doubling R&D costs has only a minor effect on net benefits, indicating that the investment is robust to higher upfront research expenditures.

Overall, the analysis shows that 3R-gene Shangi and Victoria deliver substantial economic returns under the baseline scenario and remain economically attractive even when key assumptions are made more conservative.

4. Policy priorities and opportunities for future research

Policy priorities

1. Support timely and inclusive rollout of 3R-gene varieties: The results provide a strong economic case for the timely release and dissemination of 3R-gene potato varieties in Rwanda. Delays in approval and deployment significantly reduce expected net benefits and slow potential poverty reduction. Policy and regulatory processes should therefore aim to:

- Maintain efficient timelines for biosafety review and variety release.
- Ensure that smallholder farmers in major potato zones are included from the outset.

2. Strengthen seed systems and access to 3R-gene seed: The realization of projected benefits depends on the capacity of the seed system to deliver 3R-gene Shangi and Victoria at scale and at acceptable cost. Priorities include:

- Expanding certified seed production and multiplication for 3R-gene varieties.

- Strengthening distribution networks and quality control mechanisms.
- Ensuring that farmers in all major agroecological zones, including more remote highland areas, have reliable access to quality seed.

Stakeholders have also emphasized the strategic importance of transforming other widely grown varieties (such as Kinigi) in future efforts to further expand the potential gains.

3. Enhance communication, extension, and farmer training: To fully capture cost savings and yield gains, farmers need clear guidance on how to manage the new varieties. This includes:

- Communicating that 3R-gene potatoes are designed to control late blight, while other diseases, such as bacterial wilt and viruses, still require management.
- Supporting extension services and training to help farmers adjust fungicide use appropriately, adopt good agronomic practices, and manage seed properly to maintain variety performance.

4. Ensure regulatory clarity and transparent risk communication: Regulatory clarity and transparent communication with the public are important to build trust. Policymakers and regulators should:

- Provide clear information on the safety assessment processes followed.
- Communicate the expected agronomic and economic benefits, as well as any remaining uncertainties, in a balanced way.

Opportunities for future research

As with other ex ante economic assessments, this study faces limitations linked to data availability and reliance on assumptions:

- The analysis draws on expert judgment, hypothetical scenarios, cross-sectional production budgets, and secondary data, which, while standard in ex ante work, underscore the need for ex post evaluations once the technology is released.
- The ESM does not capture externalities, such as potential health and environmental benefits from reduced fungicide use, or broader economy-wide effects on employment, income distribution, and nutrition.
- It also does not fully address market perceptions regarding whether key potato quality traits (culinary characteristics, taste, nutritional profile) are preserved in the 3R-gene varieties as breeders intend.

Future research priorities, therefore, include:

- Conducting ex post impact assessments based on actual adoption, yield, cost, and price data once the varieties are released.
- Quantifying indirect health and environmental gains from reduced fungicide use, particularly for smallholders with limited protective equipment, and from lower fungicide production and transport.
- Exploring market and consumer responses to 3R-gene potatoes to confirm that quality attributes are maintained or improved.
- Extending analysis beyond partial equilibrium to broader economy-wide frameworks when data allow.

Finally, the study underscores that the projected benefits can only be realized if institutional and organizational capacities—especially within the seed system—are strengthened. Investments in institutional readiness are therefore central to turning the potential of 3R-gene potatoes into tangible, long-term gains for Rwanda's farmers and consumers.

Authors:

Evelyne Kihiu[1]*, Jack Malit[1], Placide Rukundo[2] , Eric Magembe[1], Marc Ghislain[1], Marcel Gatto[1], Jose B. Falck-Zepeda[3], Anastase Nduwayezu [4], Athanase Nduwumuremyi[5], Claude Nshimiyimana[6], Ingabire Chantal[7].

[1]International Potato Center (CIP), Nairobi, Kenya.; [2]International Potato Center (CIP), Antananarivo, Madagascar.; [3]International Potato Center, Johannesburg, South Africa.; [4]International Food Policy Research Institute (IFPRI), Washington, D.C., United States of America.; [5]Rwanda Agriculture and Animal Resources Development Board, Kigali, Rwanda.; [6]International Potato Center (CIP), Antananarivo, Kigali, Rwanda.; [7]Director General for Planning, Ministry of Agriculture & Animal Resources, Kigali City, Rwanda.

Publication:

Ex ante economic impact assessment of the 3R-gene potato in Rwanda (Working Paper).

CIP INTERNATIONAL POTATO CENTER

CIP thanks all donors and organizations that globally support its work through their contributions to the CGIAR Trust Fund. www.cgiar.org/funders/

2026.01.004/BF