Feasibility study plant extracts in Rwanda

Developing value chains in public private partnerships

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In a mission to Rwanda in December 2017, important stakeholders from government, research institutes, universities and private enterprises were interviewed to elaborate on Public Private Partnerships (PPP), or triple helix collaborations for further development of plant extracts in the agricultural sector of Rwanda. Findings of the missions were shared in a debriefing with the ambassador and the agricultural council of the Kingdom of the Netherlands in Rwanda. During the mission, potential leads were shared with the University of Rwanda. Through the social enterprise Crosswise Works, most important issues were discussed and brought further in a workshop in January 2018, aimed at a follow up mission to the Netherlands in June 2018, and the start-up of PPP in Rwanda.
To increase business opportunities for developing plant extract chains in Rwanda, further research, preferably in PPP would be required. Pyrethrum productivity can be increased, based on increasing pyrethrin content of the flowers (now 2% in Rwanda compared to 4% in other parts of the world), and improvement of the cropping system (direct seeding instead of transplanting). Local products from Pyrethrum might also be an option to explore. Artemisia extracts for the pharmaceutical industry has the potential to diversify the current plant extract portfolio of Rwandan organizations. Government bodies in collaboration with universities and research institutes, together with the private sector should investigate whether and how the development of the value chain can be accelerated, and how a good connection to the international market can be obtained.

Keywords: Rwanda, Pyrethrum, *Chrysanthemum cinerariifolium*, *Tanacetum cinerariifolium,* pyrethrin, Artemisia, *Artemisia annua*, Artemisinin

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Photo cover: © Raymond Jongschaap
Pyrethrum drying facility in Rwanda Musanze district

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Preface

At the end of February 2017, the Top Team, led by DG AN, visited Rwanda to strengthen cooperation in the field of horticulture.

This report describes possible promising extracts from plant material from Rwanda in the field of green cosmetics, health, green crop protection and fragrances and flavours that meet the world market demand.

Follow-up steps are foreseen in collaboration between the Netherlands and Rwanda in the field of knowledge exchange and research, and the building of public private partnerships. The mission in December 2017, the workshop in January 2018 and the follow up in June 2018 are the basis for these developments.

1 Introduction

Plant extracts offer opportunities for business innovation in agriculture, and may contribute to solutions in environmental and societal challenges around human health, sustainability and food. In her Vision 2020, the Rwandan government proclaims to develop itself as a frontrunner in innovation and sustainability. This feasibility study provides insights in the Rwandan potential for developing the plant extraction industry.

In a mission to Rwanda in December 2017, important stakeholders from government, research institutes, universities and private enterprises were interviewed to elaborate on Public Private Partnerships (PPP), or triple helix collaborations for further development of plant extracts in the agricultural sector of Rwanda. Findings of the missions were shared in a debriefing with the ambassador and the agricultural council and its secretariat of the Embassy of the Kingdom of the Netherlands in Rwanda. During the mission, potential leads were shared with the University of Rwanda. Through the social enterprise Crosswise Works, most important issues were discussed and brought further in a workshop in January 2018, aimed at a follow up mission to the Netherlands in June 2018, and the start-up of PPP in Rwanda.

To increase business opportunities for developing plant extract chains in Rwanda, further research, preferably in PPP would be required. Pyrethrum productivity can be increased, based on increasing pyrethrin content of the flowers (now 1.2-2% in Rwanda compared to 4% in other parts of the world), and improvement of the cropping system (direct seeding instead of transplanting). Artemisia extracts for the pharmaceutical industry has the potential to diversify the current plant extract portfolio of Rwandan organizations. Government bodies in collaboration with universities and research institutes, together with the private sector should investigate whether and how the development of the value chain can be accelerated, and how a good connection to the international market can be obtained.

In the following sections, the findings of the mission to Rwanda are jointly presented with background literature to sustain the claims and facts of plant extracts that may be used for improved business opportunities in agriculture.

2 Quick scan agriculture and plant extracts in Rwanda

2.1 Visits

As to get a quick understanding of the agriculture dynamics in Rwanda, and the potentials for plant extracts in Rwanda, Wageningen University and Research was asked and guided by the Dutch Embassy in Rwanda for several visits to important stakeholders in the country. Interviews were held with the Horizon group and Sopyrwa group as representatives of private parties, with the Rwanda Agricultural Board and the National Agricultural and Export Board as representatives of governmental (research) organizations, and with the University of Rwanda as one of the fundamental research organisation. Apart from that, spontaneous encounters with Dutch and Rwandan entrepreneurs supported the mission.

2.1.1 Horizon Group, Kigali

During the visit, the plant extract options were discussed with the CEO of the Horizon group and Sopyrwa, Mr. Eugene Haguma. In their headquarters in Kigali, Rwanda. The history of Pyrethrum production and processing in Rwanda was explained. Shifting from Pyrethrum flower export to national processing of the Pyrethrum flowers was an important step. Apart from Pyrethrum, other essential oils are refined, e.g. lemon grass oil and Artemisia oil. As constraints, the market uptake of the essential oils were mentioned, and the seasonality of the crop production, leading to flushes in the processing chain. Sopyrwa expressed a clear need for research in the whole value chain, to get the most efficient and most profitable plant extracts for the international markets. The R&D of Pyrethrum was merely focussed on best practices, and not much experience with selection and breeding could be mentioned.

2.1.2 Rwanda Agricultural Board (RAB), Rubona

During the visit to RAB in Rubona in the southern province (Figure 2.1), there was a meeting with the, -at that time head of research division, dr Patrick Karangwa, now Director General of the Rwanda Agricultural Board. RAB screens new products (testing) and is responsible for agricultural research in livestock and arable crops. An explanation of the RAB structure and agricultural zones (east, south, west, north) was presented. Based on Agro-Ecological Zoning (AEZ), research and extension is organized in 14 research stations, to work on farmers' needs. The Agro-Ecological Zones are crop and livestock specific, with good stakeholder involvement, including NGOs and farmers' organisations.

RAB focuses on maize, rice, wheat, Irish potato and cassava, Leguminosae (common bean, soy bean) to which horticulture was added, being 8 in total. The National Agricultural and Export Board (NAEB) focuses on export crops like coffee and tea in a value chain approach.

Major topics and challenges for RAB were the pests and diseases in cassava: mainly the cassava brown streak virus (CBSV; genus *Ipomovirus; Potyviridae*). In banana the problems mainly related to bacteria, and in maize the fall army worm (*Spodoptera frugiperda)* has been an enormous threat in the 2017 short season. The combat of the fall army worm in maize, a threat coming from neighbouring countries, had generated a national movement by government bodies like the army (handpicking of larvae and worms), RAB (research), private companies like Sopyrwa (products based on pyrethrin), sprayed (most effective on small larvae) by the national air force in the 2017 short season. The fact that the Fall army worm has about 80 host plants, made it a severe threat.

Figure 2.1 *The southern agricultural zone division of the Rwanda Agricultural Board in Rubona.*

! Although the reason was a negative one (the threat of the fall army worm), combatting it nationwide has been a great success and can be seen as an example of a successful project in the golden triangle, triple-helix, or diamond, where government, private companies, the public and research organisations (have to) work together for a common cause (See Figure 2.2).

After the experience with the fall army worm the search for more affordable and durable solutions for such threats, e.g. Integrated Pest management, or research into mixed cropping systems with maize and Leguminosae, or surrounding plots with Brachiaria grasses is promoted, including IPM demonstration fields.

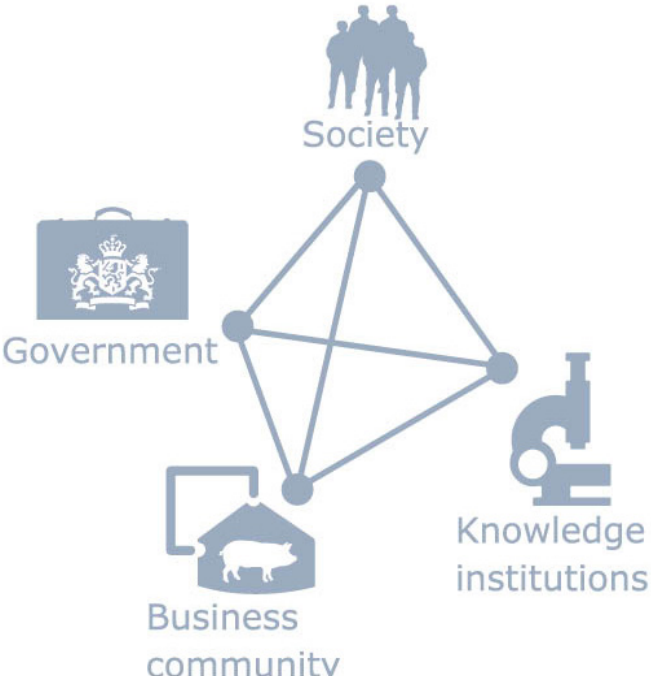

Figure 2.2 *The diamond, for successful plant extract value chain development.*

RAB is going through a process of change, where it has merged from 3 former research institutions. The government operates as an enabler for this process with the aim to have a more efficient national research institute. A specific objective of RAB is to simplify and harmonise the costing of research, and models like those used by Wageningen University & Research may serve as an example.

2.1.3 National Agricultural and Export Board (NAEB), Kigali

An interview was held in the Dutch Embassy with Mrs Assinath Uwimbabazi, essential oil specialist of the National Agricultural and Export Board (NAEB) of Rwanda. The National Agricultural and Export Board (NAEB) is responsible for the national tea, coffee and other export crop production, such as pyrethrum and essential oils and processing in a value chain approach, including post-harvest. NAEB and RAB work together on specific (agronomy) research topics in these crops.

Mrs Uwimbabazi is one of the three essential oil specialists at NAEB, who focus on Pyrethrum, Eucalyptus, Patchouli, Geranium and Tagetes oil. The marketing specialists at NAEB are considered as the most important ones in the value creation chain, although inducing resources (diversification and increasing production volumes) is considered important. Multiplication is problematic at the moment. NAEB's task is to show a clear prospective on export production chains, including cross border logistics. A specific constraint at the moment is the managing and merging of different governmental institutions. NAEB is ready, and hopes that the new policy of public private partnership (PPP) may lead to new projects.

2.1.4 University of Rwanda (UR), Kigali-Musanze

In Kigali, a small interview was held with Dr Guillaume Nyagatare, senior lecturer at the Department of Irrigation and Drainage, in the School of Agricultural Engineering and Environmental Management of the University of Rwanda. He expressed a keen interest in Public Private Partnerships, and was interested in how a university could stay objective in such a constellation, and how this could work for Rwanda. It was agreed to arrange a special meeting in at the University of Rwanda in Musanze, the following day (Figure 2.3).

Figure 2.3 *Interview with representatives of the University of Rwanda in Kigali (left) and Musanze.*

At the premises of the University of Rwanda in Musanze, Dr Raymond Jongschaap of Wageningen University & Research held a presentation "Plant Science for Impact", after which the pros and cons of Public Private Partnerships (PPP) were discussed with a group of 30 scientists and students. As in Kigali, the main concern was how to remain objective in research (partly) paid by the private sector. The experience of Wageningen University & Research may serve for demonstration purposes. It became clear that amongst university staff (Professor Thoppe Rajagopal Srinivasan), there is experience with the PPP concept which may be explored for Rwandan opportunities.

2.1.5 Sopyrwa group, Musanze

Greenhouses. The new greenhouses of the Sopyrwa group in the north of Rwanda in Musanze, were originally designed for the propagation and research on Pyrethrum (Figure 2.4). The greenhouses are mechanical and computer controlled to maintain temperature, relative humidity at the required levels. Sopyrwa wants to increase the Pyrethrum production, and the current strategy embraces the inclusion of more farmers in 5 other districts where potato farming is currently taking place. The occurrence of viable potato production system is seen as a proxy for places where Pyrethrum production could thrive as well, based on the experiences in the Musanze area.

Figure 2.4 *Horizon group mechanical and computer controlled greenhouses in Musanze.*

Potato seed multiplication. Although being built for the multiplication, research and development of Pyrethrum, the greenhouses now serve as seed potato multiplication centres, to provide local farmers with the potato seed material for their fields. The multiplication of potato seed has speed up enormously: the reproduction of 5 generations took more than 3 years in the traditional system, whereas in the new system these are provided within 1 year. The end-product (mini-tubers) are provided to the farmers, who deal with the last step of reproduction before actual planting takes place. Only the potato variety 'Kinigi' is being processed.

Pyrethrum production was introduced to Rwanda around 1937. A strip of 14,000 ha volcano soils in the north of the country in the Musanze district was distributed amongst farmers, who received 2 ha each. As much as 40% of the land was to be dedicated to the production of Pyrethrum for its flowers. The Pyrethrum production system rotates with the potato production system: 1 year of Pyrethrum production is followed by 1 year of potato production, in which 3 potato crops are grown and harvested. As a rule, farmers have divided their land 50/50 to Pyrethrum and potato production. After harvest, the potato ridges are used for transplanting the Pyrethrum plants from the other 50% of land. After the removal of the Pyrethrum plants, potato is planted in the ridges again (Figure 2.5).

Figure 2.5 *Pyrethrum production at farmers' fields in Musanze district, Rwanda.*

Advances in Pyrethrum productivity are merely based on the increase of crop density over the years. Crop density has doubled from the original planting on potato ridges at 60 x 40 cm (4.17 plants per square meter) to planting on and between the potato ridges at 30 x 40 cm (8.33 plants per square meter). It has been observed that Pyrethrum plants have to recover from the transplanting shock, and only start flowering after 5 months and continue flowering for 7 months to provide 400-500 kg of dry flower heads per hectare. The experience with seeding is that the plants already start flowering after 3 months, and continue flowering for 9 months and may reach 2000 kg of dry flower heads per hectare. This has not been confirmed by scientific experiments. The productivity increase from 500 to 2000 kg/ha may partly be explained by the gain of 2 additional production months (9 instead of 7, i.e. 30%), and by further increase of plant density by the direct seeding technique. Farmers deliver the freshly harvested flowers in bags of 30 kg, after which it is air-dried in 4-7 days and 80% of the water weight volume is lost (Figure 2.6). The pyrethrin content observed at the moment in Rwanda is 1.2-2% of the dry weight of the flower heads.

Figure 2.6 *Drying and packaging of Pyrethrum flowers in Musanze district, Rwanda.*

Quality control in Pyrethrum production is merely controlled by the timing of flower picking. Farmers are trained to pick at the right developmental stage of the flowers, but do not have a direct incentive: they are paid per weight unit, regardless of the quality (pyrethrin concentration) of the flowers.

Prices. Current prices (December 2017) for farmers are 1200 Rwandan francs per kg of dry flowers they deliver to the drying facilities, which is equivalent to ≈ € 1 or ≈ US$ 1.2. At a productivity of 500 kg dry flower heads per hectare per year, farmer income is around € 500, or US$ 600 per hectare. Current prices for the product (with 50% pyrethrin content) are about € 175 or US$ 210 per kg.

Processing. As the processing equipment of Sopyrwa (Figure 2.7) can be adapted for the extraction of a variety of oils from different species, the company has tested oil extraction from similar crops. Amongst them are Artemisia (*Artemisia annua*), Peppermint (*Mentha × piperita*), Lemon grass (*Cymbopogon citratus*), Lippia (*Lippia citriodora*), Ginger bush (*Tetradenia riparia*), Patchouli (Pogostemon cablin), Eucalyptus (*Eucalyptus spp.*), Coffee (*Coffea spp.*), Geranium (*Geranium spp.*) and Tagetes (*Tagetus minuta*). Outside their facilities, Sopyrwas has some demonstration plots where these species are grown.

Figure 2.7 *Sopyrwa plant extraction facility in Musanze district, Rwanda.*

The questions for Sopyrwa and any other private company that would like to deal with profitable value chains in plant extracts, is what can be the candidate crop, what could deliver a high volume and high quality product that can be shipped by air and how can they could penetrate the international market with the (new) products. These questions should be addressed by Rwandan stakeholders, preferably in public private partnerships.

2.2 Yield gap

The difference between actual and potential crop yield is often referred to as 'yield gap'. The inefficient use of radiation, temperature and precipitation defines the magnitude of this difference, resulting in limited productivity rates. These rates can be further reduced by the occurrence of pests and diseases. Appropriate agronomy (crop, soil and plant protection) management measures may help overcome the limiting and reducing factors.

In Africa, rainfed agricultural productivity rates can be tripled or quadrupled only by the more efficient use of the natural resources (Figure 2.8). However, social economic aspects of farmer opportunities to alleviate limitations and reductions, must not be forgotten, for instance the availability and affordability of fertilizers and crop health agents, and a well-embedded system that supports the appropriate use and application of them.

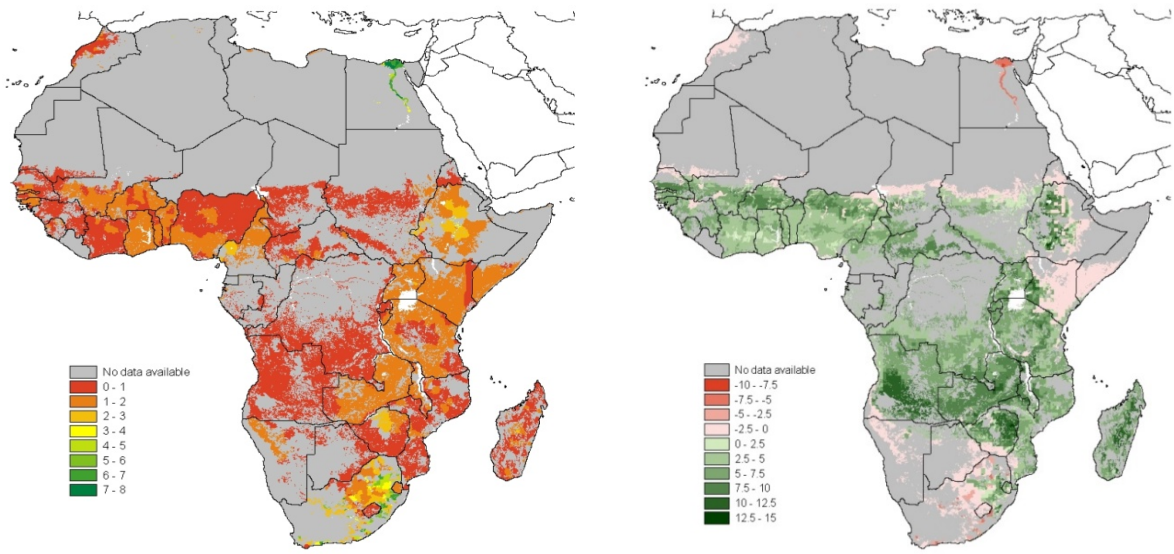

Figure 2.8 *Actual cereal yield (left) and yield gap (right) in tonnes DM per harvest in Africa. Yield gap expressed as difference between actual national average and potential cereal crop yield per region (Conijn et al., 2011).*

Given limited land and water resources available for crop production and global population soon to exceed 9 billion, ensuring food security while protecting carbon-rich and biodiverse rainforests, wetlands, and grasslands depends on our ability to increase current crop yields on existing farmland through sustainable intensification. The Global Yield Gap and Water Productivity Atlas (GYGA) provides robust estimates of untapped crop production potential on existing farmland based on current climate and available soil and water resources (GlobalYieldGapAtlas, 2017).

In Figure 2.9, the maize yield gap (tonnes DM per harvest) in Rwanda is shown, expressed as difference between actual national average and potential maize crop yield per region (Conijn *et al.*, 2011).

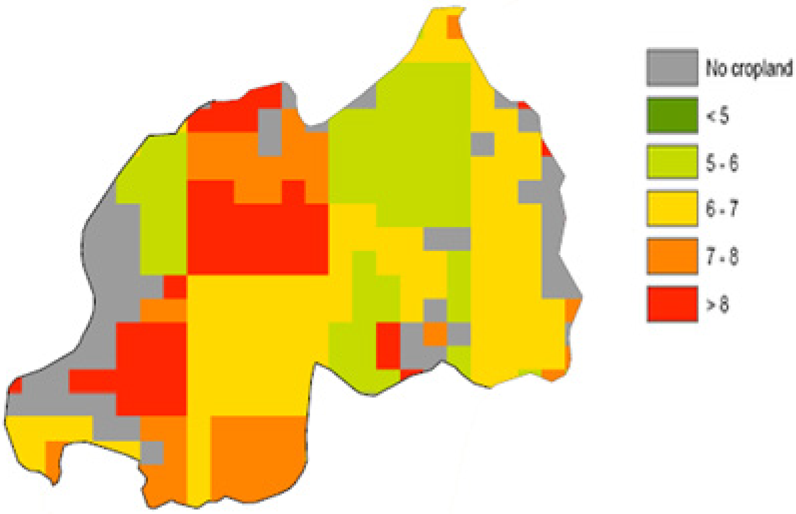

Figure 2.9 *Maize yield gap (tonnes DM per harvest) in Rwanda, expressed as difference between actual national average and potential maize crop yield per region (Conijn et al., 2011).*

From Figure 2.9, the potential for further productivity increase can be addressed. To succeed, universities, research institutes, extension services and input providers of fertilizers and crop health agents, should collaborate to become a well-embedded system that supports the application of appropriate agronomy measures. They should also collaborate to provide affordable fertilizers and crop health agents, and advice how to use them.

With regards to alleviate yield reduction effects of pests, especially from insects, the development of an affordable local product on the basis of Pyrethrum is an option that may be explored.

3 Plant extracts

From the mission, there are 2 clear cases to further develop the plant extract value chain in Rwanda, although other plant extracts may also be developed. However, on the basis of current dynamics, opportunities and willingness to take steps forward, focussing on a few products is required.

1. **Improvement of Pyrethrum production**, where emphasis should be put on the efficiency increase of the current pyrethrum production systems which is integrated in the potato production system. Changes in crop management will increase resource use efficiencies resulting in higher biomass production, whereas investments in breeding and selection may lead to further increase of pyrethrin content in the flowers and pyrethrin yield per hectare, a strategy that has been proven effective in Australia. Product diversification, for instance a low-cost product for the local market in Rwanda might be an interesting option to develop.
2. **Start-up of Artemisinin production**, where emphasis should be put on the introduction of the crop in suitable areas where the whole value chain can be (cost) efficiently developed. In parallel, agronomy and extraction processes should be optimized and (international) market access should be targeted.

In the following paragraphs, both crops and opportunities are described in more detail.

3.1 Pyrethrum (*Tanacetum cinerariifolium*)

3.1.1 Characteristics

The perennial herbaceous plant *Tanacetum cinerariifolium*, also known as pyrethrum, is a daisy-like flower with an inherent ability to produce considerable amounts of biologically active metabolites, especially pyrethrins, probably intended for self-defence. It is also known as *Chrysanthemum cinerariifolium* and originates from the Balkan (Dalmatia).

Pyrethrum is a cash crop grown for its natural pyrethrins which are used in formulating insecticides. The dried flowers are ground, as they contain the active components pyrethrins in the seed cases, which are extracted and sold in the form of an oleoresin. Pyrethrins attack the nervous systems of insects and has advantages over other insecticides, as it has repellent effect, exhibits rapid effects, and is non-persistent in the environment and hence recommended by the World Health Organization (WHO) for export horticulture and fruit production due to its low Minimum Residue Levels (MRLs) (HighChemAgriculture, 2014).

The discovery of pyrethrin toxicity towards insect pests triggered the exploitation of pyrethrum for commercial purposes in the late 19th century. Despite having a long history of safe and effective use as a source of a versatile botanical insecticide, pyrethrum lost its popularity when, in the mid-20th century, more cost-effective, active and persistent synthetic variants became available. In recent years, a shift in general consumer preferences towards more selective, safer, non-persistent and more environment-friendly pesticides has renewed interest in the use of pyrethrum, renewing pyrethrum's economic significance (Jongsma and Ramirez, 2017).

Pyrethrin is considered to be amongst the safest insecticides for use around food. It is one of the most commonly used allowed non-synthetic insecticides in certified organic agriculture. Pyrethrins are gradually replacing organophosphates and organochlorides as the pesticide of first choice. They are not persistent, being biodegradable, and break down on exposure to light or oxygen (HighChemAgriculture, 2014).

3.1.2 Productivity

In Rwanda, new production strategies have led to doubled production results. Farmers are organized into small manageable farmers' cooperatives for production, drying and collection of pyrethrum flowers. Improved sun drying system for quality preservation, good agricultural practices, improved clones (in vitro produced plantlets), soil fertilisation for better productivity were achieved and seedlings produced are distributed to farmers free of charge. Land use consolidation and crop intensification programs have been achieved from 2010 and with this system, the production was doubled (Mureramanzi and Bizimungu, 2015). In Annex 1 (Pyrethrum: A traditional cash crop being revived) an article in the African Research Bulletin (AFP, 2014) has shed some light on recent national ambitions in Rwanda.

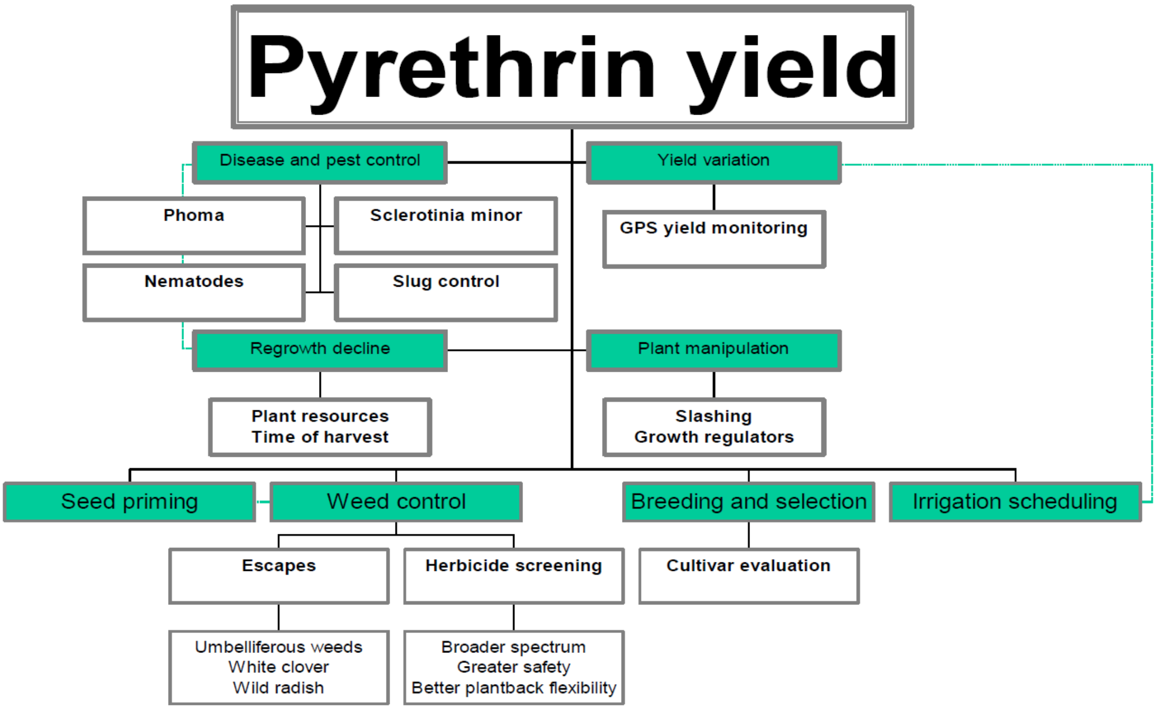

Figure 3.1 *Pyrethrin yield dependency and research focus in Australia (Groom et al., 2015).*

In Australia, in a timespan between 1997 and 2010, Pyrethrum moved from an experimental crop to a sophisticated broad field production model (Figure 3.1): as a result Pyrethrum crop yield increased by 79%. A major change was moving from high cost production system on splits and transplants of 4-5 plants per m2, to a lower cost system based on direct seeding at higher plant densities assisting in weed control and increasing yields, with a new set of agronomic challenges (Groom *et al.*, 2015).

The aim was to produce high quality seed, develop effective weed control methods, overcome several disease problems and efficiently mechanise the harvesting process. High quality seed was produced by timing harvests and optimising seed cleaning methods. Seed drill performance were optimized for productivity and weed control. An effective management programme was set up to combat ray blight, a disease caused by *Phoma ligulicola*. Root node nematodes have been a problem in Pyrethrum since decades (Parlevliet, 1971). Apart from nematodes, Pyrethrum is affected by several pests including trips, aphids, red spider mites which affect the production of quality. Nematodes are managed by crop rotation and use of nematicides (HighChemAgriculture, 2014). Crop response to irrigation during moisture stress was effective for specific key times in the growth cycle. Natural drying of windrowed plants was most effective.

Despite the fact that the plant has been under commercial cultivation in many parts of the world for the last 160 years, surprisingly little breeding, ecological and genetic work has been performed to achieve important economic targets of the industry. Increasing the yield of pyrethrins in its natural host, or the mass production of pyrethrins in cultured cells or even a microbial host, would offer new possibilities to the pyrethrin industry that could potentially contribute to placing pyrethrins in a more favourable competitive position in today's insecticide market. Similarly, insights into the biological role of secondary metabolites found in pyrethrum could potentially greatly benefit the economics of the pyrethrum industry (Jongsma and Ramirez, 2017).

In an era in which advanced breeding and genetic modification techniques are not the limiting factor, the lack of basic biochemical information, such as the identification and isolation of key enzymes involved in the formation of pyrethrins and sesquiterpene lactones, constitutes the major hurdle in the genetic engineering of these secondary metabolites, in either the natural host or other species. Genes encoding enzymes involved in the biosynthesis of certain metabolites are expected to be actively transcribed at specific moments and/or specific tissues; hence, the determination of the exact site of accumulation and synthesis of secondary metabolites constitutes a necessary tool to help pick out genes of interest. Developing knowledge around different aspects of pyrethrum secondary metabolism will, therefore, contribute to generating the necessary tools for breeding and/or engineering of varieties with enhanced pyrethrin content and decreased content of unwanted metabolites. Potentially, in the longer run, it will also be possible to engineer the biosynthesis of pyrethrins into other crop species. Ideally, such crops would then no longer require the external application of pesticides to protect them against microbial diseases and pests. Here, we will discuss the most important findings obtained in our lab, ranging from localization and biochemical aspects of the synthesis of pyrethrum defence compounds to their possible biological role in the young emerging seedling as well as in the adult plant (Jongsma and Ramirez, 2017).

3.1.3 Market opportunities

New product development with pyrethrins include residential mosquito misting systems, organic farming and microencapsulation for use in food processing plants and warehouses. There are also other properties of pyrethrum that may lead to new and more unique products in the immediate future (Carlson, 2015). The development of an affordable local product on the basis of Pyrethrum is an option that may be explored.

3.2 Artemisia (*Artemisia annua*)

3.2.1 Characteristics

Artemisinin herb is native to China and is found to be effective against malaria parasites. Ongoing research and development has also found artemisinin and its derivatives to be effective against the treatment of cancer. Treatment of acanthamoebiasis is simultaneously effective against both developing forms (trophozoites or cysts) of amoebae in animals (Derda *et al.*, 2016). Artemisinin and its derivatives, with their established safety records, form the first line of malaria treatment via artemisinin combination therapies (ACTs). In addition to its antimalarial effects, artemisinin has recently been evaluated in terms of its antitumor, antibacterial, antiviral, antileishmanial, antischistosomiatic, herbicidal and other properties (Pandey and Pandey-Rai, 2016). However, low levels of artemisinin in plants have emerged various conventional, transgenic and nontransgenic approaches for enhanced production of the drug.

3.2.2 Productivity

Extensive efforts have been made to improve artemisinin synthesis through different approaches. The recent advancement in both conventional and modern approaches of in-planta yield enhancement are seen as (i) metabolic engineering of the plant using various genetic engineering tools; (ii) regulation of artemisinin biosynthesis through stress signals to plants, hairy root cultures and cell cultures and (iii) conventional, mutational and molecular breeding of *A. annua* (Pandey and Pandey-Rai, 2016). In different experiments, the stress signals for artemisinin enhancement with positive effects came from treatments as drought, chilling, night frost and salinity, a deficiency of potassium and treatments with specific nutrients (B, As, P, Cd) and acids, sugars and hormones, yeasts treatments with UV-B and UV-C, and post-harvest drying (Pandey and Pandey-Rai, 2016).

As an average, 8 grams of artemisinin can be extracted per kg of dried leaves (0.8%) of *A. annua*. Breeding has boosted this figure by 3 times to 24 grams per kg, whereas others have identified key Artemisia genes that could optimize agricultural yields, robustness or other desirable traits when the plant is grown in different areas of the globe to create plants that produce up to 50% more artemisinin per kilogram of leaves than the best commercial variety (Graham *et al.*, 2010).

For the production of high-yield varieties of *A. annua*, a fast track molecular breeding project known as 'The CNAP Artemisia Research Project' has been initiated at the Centre for Novel Agricultural Products (CNAP) which is a part of university of York. With the aim to produce high yielding non-GM variety of *A. annua*, over 23,000 parental lines were screened for desired traits and 768 different hybrid crosses were made, of which 268 most promising hybrids were forwarded to field trials. After rigorous selection procedure, two best performing hybrids viz. Hyb1209r (Shennong) and Hyb8001r (Zenith) with 36.3 and 54.5 kg/ha artemisinin have been commercially released (Pandey and Pandey-Rai, 2016).

One tonne of artemisinin gives about 2 million doses of artemisinin based combination therapy (0.5 gram per dose).

3.2.3 Market opportunities

According to a report summary (GVR, 2017), Artemisinin market is expected to witness substantial growth over the forecast period owing to its increasing application scope in pharmaceutical industry. Market for artemisinin is segmented on the basis of its applications in treatment of malaria, cancer and helminth parasites. Largest application in 2013 was artemisinin based combination therapy (ACT) in treatment for malaria. Market can also be segmented on the basis of its production mechanism as biosynthesis, chemical synthesis and synthesis in engineered organisms. Intensive research activities have developed new and economical methods of artemisinin production (Ro *et al.*, 2006). However, the demand for malaria drugs soars (van Noorden, 2010), and synthetic malaria drug meets market resistance (Peplow, 2016).

Demand for artemisinin has grown considerably over the past decade following the recognition of ACT by the World Health Organization (WHO) as a first line treatment for malaria. Increase in R&D activities and growing medical infrastructure particularly in emerging economies including China and India has triggered demand for artemisinin and its derivatives. Rising demand from malaria endemic countries such as Congo, Nigeria, Tanzania, Uganda and other South-East Asian countries including India is expected to drive market for artemisinin and its derivatives over the next six years (GVR, 2017).

However, market for artemisinin is still in nascent stages owing to limited number of global manufacturers. In addition, lack of funding and programmatic uncertainties coupled with demand-supply gap are further expected to hamper market growth over the forecast period. According to recent research (Shretta and Yadav, 2012), a mix of strategies is required to stabilize the artemisinin and ACT market: first, better and more effective pooling of demand and supply risks and better contracting to allow risk sharing among the stakeholders are needed. Physical and financial buffer stocks will enable better matching of demand and supply in the short and medium term. Secondly, physical buffers will allow stable supplies when there are procurement and supply management challenges while financial buffer funds will address issues around funding disruptions. Finally, in the medium to long term, significant investments in country level system strengthening will be required to minimize national level demand uncertainties. In addition a voluntary standard for extractors to ensure appropriate purchasing and sales practices as well as minimum quality and ethical standards could help stabilize the artemisinin market in the long term (Shretta and Yadav, 2012).

Asia Pacific and Africa held the largest market share for artemisinin and its derivatives owing to the large production base of artemisinin herbs coupled with growing demand for artemisinin based therapy in malaria endemic countries. North America held the second largest market followed by Europe on account of well-developed medical industry coupled with large number of pharmaceutical units.

Key companies that manufacture artemisinin and its derivatives include Yeshua-Bio-Tech, Guilin Pharmaceutical Co. Ltd, Sanofi Aventis, Shanghai Desano Chemical Pharmaceutical Co. Ltd, Kunming Pharmaceutical Corporation, Calyx Pharmaceuticals and Chemicals and Mylan Laboratories Limited.

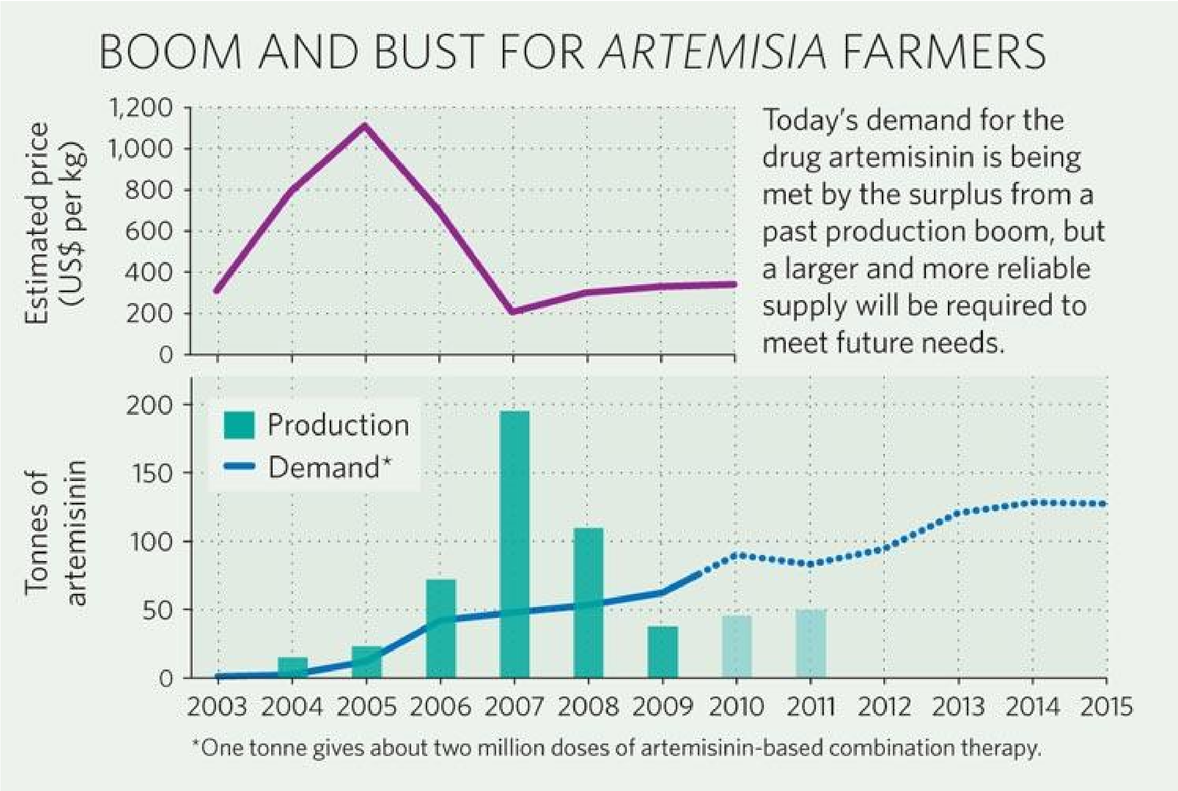

Figure 3.2 *Production (top) and demand (bottom) and estimated price of artemisinin (van Noorden, 2010).*

3.3 Plant extract value chains

Lessons in smallholder farmer participation in the pyrethrum industry in Tanzania show that unless group bulking arrangements are enhanced to meet market requirements, while also rewarding individual farmers' efforts to achieve the required product quality, smallholder farmers will have little incentive to comply with best practice standards. By facilitating group supply strategies and by having transparent pricing structures, there will be greater trust and commitment by smallholder growers participating in the pyrethrum supply chain (Munyeche *et al.*, 2013).

4 Recommendations

4.1 Organizational

- The past experience of the joint action against the Fall army worm has been born out of necessity, to combat an immediate threat. Either willingly or forced, various organizations of different origin have experienced what it is to work together for a common cause. It is recommended that this experience is used for a new (good) cause: the rapid advance of the development of Rwanda small and medium sized enterprises, in collaboration with the government and research institutions to develop opportunities for business innovation in agriculture, especially in plant extracts that may contribute to solutions in environmental and societal challenges around human health, sustainability and food.

4.2 Opportunities for plant extracts

- The growth, production and processing of various plant species seems limitless in Rwanda. Almost all climate/soil combinations that favour specific plant species can be found and should be optimized for high resource use efficiency. This requires Agro Ecological Zoning and further research into the agronomy of specific plant species. There is ample scope for improvement, based on current insights in the efficiencies for rainfed agriculture in Africa.
- With regards to the plant extract varieties that are currently being exploited in Rwanda, pyrethrum is the one with the largest track-record. Progress is being made in optimizing resource use efficiency in its current production system, which is limited by the rotation with potato. It seems that quality improvement should be investigated: the pyrethrin content of flower heads can be improved by picking at the right development stage, but farmers do not seem to have an incentive here, as they are paid out on a weight basis, and not on the pyrethrin yield.
- There is a transition going on from a system where adult perennial pyrethrum plants are uprooted after being in production for a year, and then replanted in and in between the ridges in potato fields, where 3 potato cycles have been completed in that same year to direct seeding of Pyrethrum. Although it seems that direct seeding has an advantage over transplanting in terms of productivity, it is not known how this affects the pyrethrin content in the flowers, as a result of crossing-out the yield components that were selected for over the years.
- With regards to alleviate yield reduction effects of pests, especially from insects, the development of an affordable local product on the basis of Pyrethrum is an option that should be investigated.
- As potential new value chain, the start-up of Artemisinin production is recommended. Emphasis should be put on the introduction of the crop in suitable areas where the whole value chain can be (cost) efficiently developed. In parallel, agronomy and extraction processes should be optimized and (international) market access should be targeted.

4.3 Conclusion and follow-up

To increase business opportunities for developing plant extract chains in Rwanda, further research, preferably in public private partnerships would be required. Pyrethrum productivity can be increased, based on increasing pyrethrin content of the flowers (now 2% in Rwanda compared to 4% in other parts of the world), and improvement of the cropping system (direct seeding instead of transplanting). Local products from Pyrethrum might also be an option to explore. Artemisia extracts for the pharmaceutical industry has the potential to diversify the current plant extract portfolio of Rwandan organizations. Government bodies in collaboration with (international) universities and research institutes, together with the private sector should investigate whether and how the development of the value chain can be accelerated, and how a good connection to the international market can be obtained. Wageningen University and Research is willing to take the role as international partner.

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Annex 1 Pyrethrum: A traditional cash crop being revived

An article in the African Research Buletin (AFP, 2014) has shed some light on recent national ambitions in Rwanda:

Rwanda is working to diversify its economy with a natural insecticide farmed on its fertile foothills. Pyrethrum is ideally suited to the climate in the foothills of the Virunga mountains in the north of Rwanda. Few grow the plant commercially: only in Rwanda, in neighbouring Kenya and Tanzania and in Australia, mainly on the island of Tasmania. The revival of this crop, first introduced in colonial times, is one of Rwanda's recent attempts to diversify its sources of foreign currency, generated mainly by tea, coffee and tourism. Agriculture still accounted for one-third of the economy of this densely populated central African country in 2012.

"Rwanda decided to develop pyrethrum as a cash crop, so as to get an additional source of revenue for farmers and another foreign exchange earner," Jerome Mureramanzi, production manager at the Rwanda Pyrethrum Company (Sopyrwa) told AFP.

Pyrethrum was first introduced here as a crop in 1936, but dropped off after Rwanda's devastating 1994 genocide, only being revived a decade or so later. The pyrethrum is exported to the United States, Europe and Asia, while some is sold to a local company that produces organic insecticides.

Environmental considerations were a factor motivating its revival.

"As the world becomes more conscious of the need to protect the environment, Rwanda has seized the opportunity to develop this natural insecticide," Mureramanzi added.

The plant, from the chrysanthemum family, contains the organic substance pyrethrin, which acts on the central nervous system of insects.

"Pyrethrum kills a wide variety of insects without any impact on the environment, as its organic compound is very quickly destroyed by ultraviolet rays," Mureramanzi said.

The flowers are dried and processed, then the honey-coloured extract is exported.

Between 2009 and 2013, annual production of dried flower heads rose from 200 tonnes to 1,300 tonnes, according to Sopyrwa, with revenue rising seven fold to $7m.

The plant will not grow at altitudes lower than 1800 metres and needs cold nights and generous rainfall. This region of rich volcanic soil where northern Rwanda meets Uganda and neighbouring Democratic Republic of Congo, with its lashing rain and chilly nights, fits the bill exactly.

Some 37,000 Rwandan peasant farmers live from this crop, cultivation of which covers some 3,000 hectares.

Under the terms of a deal between the government and the farmers, some of the farmers have to use at least 40% of their land for growing pyrethrum.

The remaining 60% can be planted with food crops, while the farmers are also obliged to alternate so that pyrethrum is not planted on the same part of every plot the whole time.

Sopyrwa's director general Gabriel Bizimungu said that the company provides its farmers with seeds and fertiliser, builds drying stations for the flowers and pays its farmers on time.

The programme, funded by USAID and Wisconsin-based cleaning products manufacturer S.C. Johnson, has been training farmers since 2009 on how to increase yields and improve the quality of the pyrethrum flowers they cultivate.

Farmers get virtually the same profits as they do from growing potatoes and alternating crops means the productivity of food crops is improved. (© AFP 4/2 2014)

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Report WPR-801

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The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to inding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 5,000 employees and 10,000 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.