The Next Generation of Biopesticides: Institutional barriers and enablers to co-innovation in a science and commercialisation programme

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Abstract: The international market for biopesticides is growing rapidly. Biopesticides are not widely used in New Zealand as there are few available that target New Zealand's pest complexes, production systems and regulatory hurdles. The Next Generation Biopesticides programme aims to develop and commercialise biopesticides for NZ's pastoral, horticultural and arable sectors. A multi-level institutional framework was used to diagnose the enablers and barriers to co-innovation within the NGB programme and the biopesticides innovation system. Data were gathered through semi-structured interviews and during three workshops. The results showed differences between sectors in their perception of the programme and the use of co-innovation based on: i) institutional incentives for co-innovation within research organisations; ii) ownership of IP and technologies by stakeholders; iii) differing levels of urgency for new biopesticide solutions in each sectoral innovation system; and iv) the ease with which biopesticides integrate into the sector value chains.

Keywords: co-innovation, complexity, biopesticides, agricultural innovation systems, institutional dimensions

Introduction

Concern over human health, environmental impacts and the emergence of pesticide resistance has led to many synthetic pesticides being withdrawn from the market. These pesticides are not being replaced by new chemicals because of escalating development and registration costs (Borel 2017). Without alternative measures for control of insect pests and diseases, growers will be faced with crop losses estimated to be as high as 48-83% (Oerke & Dehne 2004). Biopesticides (pesticides based on microorganisms or their bioactives) are increasingly filling this gap, as the international biopesticide market continues to expand rapidly (Hynes & Boyetchko 2006; Bailey, Boyetchkoa & Längle 2010). Historically biopesticides have been successful niche products (for example in the organics industry), but their potential for transitioning into mainstream agriculture and horticulture is reflected by multiple recent acquisitions of biopesticide companies by large agrichemical companies and significant new investment in research in this space (Bailey, Boyetchkoa & Längle 2010).

Currently New Zealand's primary producers are striving to increase export earnings while at the same time are under increasing pressure to reduce their environmental footprint. All are vulnerable to major production losses caused by insect pests and diseases resulting from impending withdrawal of synthetic pesticides, emergence of new pests as a result of system intensification and/or climate change, or incursion of exotic pests (Goldson et al. 2015). However, while global use of biopesticides is increasing, they are still not widely used in New Zealand, with only a limited number of products currently being actively marketed and used by growers (O'Callaghan, Wilson & Zuydenbos 2015). There are few biopesticide products available internationally that target New Zealand's pest complexes and importation of biopesticides involves significant regulatory hurdles. As such there is a strong need for New Zealand appropriate biopesticide products.

The Next Generation Biopesticide (NGB) programme aims to develop biopesticides for the most production-limiting and intractable pests and diseases as identified by the pastoral, horticultural and arable sectors. Target pests and diseases include the devastating disease Psa-V in kiwifruit, and emerging pests of pasture, forage brassicas and arable crops. The research in the programme is being undertaken by a multi-disciplinary team of researchers from AgResearch, Lincoln University and Plant and Food Research. The research is using innovative approaches to deliver prototype biopesticides capable of rapid knockdown of pests, with multiple modes of action to target pest complexes and prevent development of resistance. Another key aspect of the research is the development of cost effective formulations and delivery systems that are safe and compatible with current end-user practice. Early prototypes with demonstrated potential (satisfactory field efficacy and cost-benefit ratios) are passed on to appropriate partners for commercial development. The six-year programme, which is largely New Zealand government funded, was conceived of and developed in partnership with several key stakeholders. These

include commercial companies and leading grower-levy funded organisations, all of which contribute co-funding. NGB programme research direction and progress is monitored by an Industry Advisory Group (IAG) composed of representatives of these co-funding organisations, together with commercial leads from each research organisation. The research is carried out in three sector-aligned themes: 1) pasture, where the team is developing biopesticides for economically damaging soil-dwelling insect pests of pasture and forage crops such as brassica; 2) arable, where research is focussed on management of pests and diseases of maize using endophytic microorganisms; and 3) kiwifruit, developing beneficial root inoculants and a foliar spray biocontrol for management of bacterial canker disease, Psa-V.

The NGB programme is highly complex; not only is the science of biopesticides complex, but the effectiveness and useability of the technologies are often contested by various stakeholders, including end-users. Moreover, the programme is running across different primary industry sectors – pastoral, arable and horticultural, and all of the stakeholders involved have their own goals, requirements and perceptions around the efficacy of biopesticides. A co-innovation approach was chosen to work within this complexity (Vereijssen et al. 2017a). In this paper we describe the institutional enablers and barriers to taking a co-innovation approach in the research and commercialisation aspects of the NGB programme, as perceived by the stakeholders in the NGB programme, and show how these perceptions are influenced by the institutions within which they operate.

Theoretical framework: co-innovation and institutions

A reason for choosing a co-innovation approach in the NGB programme is that it deals with the:

> earlier identified shortcomings of using a science-driven, linear, technology transfer-oriented approach to innovation in New Zealand (i.e. lack of end-user involvement creates a low adoption of technologies, because these do not fit in farming systems and no effort is made to create an enabling context for adoption) (Turner et al. 2016, p. 99).

The co-innovation approach is often used for solving complex problems in the agricultural sector (Rijswijk & Percy 2015), as it encourages the interactions of multiple actors, like many participatory approaches (Turner et al. 2013), but distinguishes itself by taking multiple dimensions (e.g. biophysical, social-cultural, economic, political) across different levels (e.g. local, regional and national) into consideration (Spielman, Ekboir & Davis 2009; Schut et al. 2015). The implementation of co-innovation can follow nine guiding principles, whereby inclusiveness of relevant actors throughout the value chain, a shared understanding of issues and problems, and joint learning are critical (Coutts et al. 2017; Klerkx et al. 2017). The relevant actors thus become 'co-developers of knowledge, champions of combined technological and institutional change and entrepreneurs experimenting with new business models' (Turner et al. 2016, p. 100).

Despite having guiding principles, the process of co-innovation is not necessarily easy, as its practice depends on the structure of the Agricultural Innovation System (AIS) (Turner et al. 2016). An AIS can be defined as:

> a network of organisations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organisation into economic use, together with the institutions and policies that affect the way different agents inter-act, share, access, exchange and use knowledge (Hall et al. 2006, p. vi–vii).

Hence an AIS performs a number of functions, enabled by actors, their interactions, infrastructure and institutions (together referred to as structures) (Wieczoreck & Hekkert 2012), which either enable or hinder innovation.

The structural elements of an AIS are taken into consideration when implementing co-innovation, and hence the role of supporting institutions is considered important (Turner et al. 2016). The actual influence of institutions on achieving impact has thus far had little attention (Klerkx et al. 2017). Institutions are described as 'the rules of the game' that govern behaviour (North 1991), i.e. both informal rules such as routines, traditions, and shared expectations, as well as formal rules like laws, regulations and property rights (North 1991; Hall et al. 2003). Institutions occur at several levels in which actors operate: personal, community and organisation, and AIS (Hall et al. 2003; Klerkx et al. 2017). Moreover, each institution consists of a number of dimensions as described in Table 1. Following the example of Klerkx et al. (2017), we describe the following institutional dimensions for each sector (pastoral, horticulture and arable): personal, research team, organisation, NGB programme, biopesticide history and AIS (see Table 1). The original framework by Klerkx et al. (2017) also describes country-specific norms as part of the AIS. These have been already described for New Zealand in Turner et al. (2016) and so were not revisited.

Table 1. Institutional levels and dimensions

Institutional level	Institutional dimensions	Institutional dimensions NGB
A. Personal	Professional identities, roles and routines	1. Personal: professional identities, roles and routines of stakeholders involved in the NGB programme
B. Community and Organisation	Organisational rules and regulations; rewards and (dis)incentives; procedures set by the research organisation, the programme, and the research funder	2. Research team: the research team procedures and expectations of the research team per sector
		3. Organisation: the regulations, procedures and expectations of the different organisations involved
		4. NGB programme: the programme procedures and expectations under which the researchers and other involved stakeholders per sector
		5. Biopesticide history: historical rules and norms of past projects on biopesticides prior to NGB per sector
C. Agricultural Innovation System	The institutional environment of the national AIS in countries;	6. AIS: the institutional environment for agriculture in New Zealand

Source: Adapted from Klerkx et al. 2017, p. 278 and p. 282. NGB: Next Generation Biopesticide programme; AIS: Agricultural Innovation System.

Methodology

This research was undertaken in line with co-innovation, hence it was important to ensure that when gathering data, all stakeholders were involved and their views could be sought. Thus the data presented is based on: (1) nine semi-structured interviews with members of the IAG and key people in the research team; (2) three workshops involving the researchers, IAG and a broader range of stakeholders; and (3) observations by the authors.

The interviews focussed on individual and organisational perceptions of the first two years of the NGB programme and the co-innovation approach. The hour-long interviews were held face-to-face or by phone. The interviewees' responses were captured in the notes taken by the authors and recordings. Questions for the interviews were developed in conjunction with other co-innovation research being undertaken (Turner et al. 2016) and were adapted to reflect the specific context of the NGB programme. Copies of the questions can be obtained from the corresponding author on request.

The three workshops are outlined below. Data gathered at three workshops included information from activities such as stakeholder identification and creating a programme logic model (McLaughin & Jordan 2010) for each part of the programme, as well as from the notes of the workshops and the feedback sheets that were completed by the workshop participants.

Workshop one was held with the research team during the first year of the programme, in July 2014. This workshop aimed to generate a better understanding among the researchers of the co-innovation approach used in the NGB programme. This was done through the use of the Impact Planning Tool (AgResearch 2014) and the stakeholder matrix (Victorian Department of Primary Industries 2009). These tools were used to determine the key industry, research, end-user and government stakeholders and their roles in delivering impacts from the NGB Programme.

Workshop two was with the IAG in August 2014. A similar process to workshop one was used, emphasising the co-innovation approach. The IAG were asked to validate the stakeholder analysis created by the research team and to complete the list developed in workshop one.

The third workshop was over two days in May 2015. The research team, the IAG and other relevant stakeholders met to discuss the progress of the NGB programme. Time was set aside to discuss and validate the interview results (from above), as well as to plan the coming year. Programme logic models (McLaughin & Jordan 2010) were developed to help ensure that there was an outcome focus across all the different parts of the NGB programme. The use of programme logic models supported the co-innovation approach being taken by the NGB programme by highlighting the need for stakeholders to be part of the programme development discussions and activities.

Data were analysed using the framework outlined in Table 1 (Klerkx et al. 2017), by assessing the institutional context surrounding the NGB programme. This provided a means of highlighting similarities and differences in perceptions of co-innovation across sectors involved in the NGB programme.

Results

The findings by institutional dimension (Klerkx et al. 2017) are presented in Table 2 and discussed below.

Personal dimension

This first dimension focusses on the professional identities, roles and routines of stakeholders (including the researchers) involved in the NGB programme. During the first two workshops it was noticed that both the researchers and the industry partners did not feel skilled in implementing co-innovation. One of the researchers commented that he was worried that taking a co-innovation approach would use up budget for his research. Both groups of people were focussed on what they did best, e.g. doing the research for research purposes, or from an industry perspective for commercialization purposes. Each group considered their focus more important than the co-innovation aspect of the programme.

Research team dimension

For the research team, the focus on biopesticides was both interesting (as a research topic) and necessary in terms of decreasing the use of pesticides. One researcher commented that the aim of the NGB programme was 'reducing the dependency on chemicals and growing the options for organic sectors'. Another said the aim was 'Trying to get solutions to farmers in NZ as pesticides get taken off the market and they need something to fill the gap'. Both comments point to the research teams being convinced of the need for biopesticides. Although there was a sense of progress, in terms of achieving these aims they realised it was still early in the programme for science results that could be commercialised. Researchers were focused on specific issues such as finding appropriate farmers and growers to be involved in trials, and the challenges of producing enough biopesticides for those trials. Although the focus on science was appreciated by the industry partners, it was commented by one of them that some researchers had 'no commercial bone in their body'. Although this could be seen as negative, it also illustrates the composition of the team needed for biopesticides and the importance of considering route to market for products.

The research team dimension also covers the collaboration required across research organisations. While all researchers are used to collaborating with other researchers, often from other organisations, this particular project combined not only different disciplines, but also different sectors. Hence, there were some new relationships between researchers from different organisations working together in the biopesticide space. The high level of collaboration required for the development of biopesticides was relatively new in the arable and pastoral sectors, although one interviewee commented that the approach was working: 'Real innovation happens at the project level… collaborative bunch who are working together well'. Besides the new collaborations within the sectors, the collaboration across sectors provided for an extra learning opportunity by sharing insights and having science-based discussions, although this opportunity was to some extent hampered by confidentiality agreements of the industry partners around IP. Despite that the research teams in the three sectors were getting more used to (cross sector) collaboration, whereas in a precursor programme they were largely working separately from each other. Use of the programme logic models helped research teams begin to recognise the range of stakeholders that may be critical to achieving change.

Organisation dimension

The organisational regulations, procedures and attitudes of the different organisations involved also played a big role in the NGB programme. Early in the life of the programme, two commercial partners decided to discontinue their investment in the NGB programme, due to a change in leadership and strategies within their organisations. This immediately had financial consequences and put pressure on the programme to find new co-funding and decreased the level of trust between the involved organisations. Interestingly, the lower the perceived need was for co-innovation, the less trust the stakeholder seemed to have in the other industry organisations, as trust is a key element in co-innovation processes.

Table 2. Institutional dimensions influencing the NGB programme

	Personal	Research team	Organisation	NGB programme	Biopesticide history	AIS
General findings	All directly involved stakeholders give priority to their own interest, i.e. research or commercialisation of biopesticides	Little collaboration across the research teams per sector at the beginning of the programme A need for developing relationships across research organisations in relation to biopesticides	Differing levels of support for co-innovation within organisations, which results in different levels of trust	Co-innovation creates challenges for both research and commercialisation. For example, concerns over ownership of IP and technologies by various (sometimes competing) stakeholders Finding a route to market, and having sufficient funding to do the research remains challenging Differing levels of urgency for new biopesticide solutions in each of the sectors	Complex history with failures and successes impacts on the implementation of the NGB program and its (perceived) potential success	Differing levels of ease with which biopesticides could be integrated into the sector value chains Regulatory issues could impact on commercialisation of biopesticides Small market cf. rest of world
Stakeholder findings: Research team	Differing level of willingness to engage in co-innovation processes Did not feel skilled in implementing co-innovation	Researchers from a range of organisations working together on projects Used to working across organisations in other project areas, but have found it challenging for biopesticides	Different priorities and processes in the organisations involved Some researchers conducive to co-innovation, others focused on commercial potential History of working separately on biopesticides in each organisation rather than cross organisations		Although acknowledging complex issues, focused on research problems (e.g. difficulty of getting supply of biopesticide once one had been identified, especially in pastoral space)	Funding concerns
Industry partners	Differing level of willingness to engage in co-innovation processes	Happy with research team and commitment to high quality research	Looking for opportunities to commercialise effective biopesticide products	Focus on commercial success Collaboration and sharing information do not go together with commercialisation and IP (free-riders)	Need for commercial success Tension between industry partners involved initially and those bought in later	Regulatory concerns

	Personal	Research team	Organisation	NGB programme	Biopesticide history	AIS
Sector findings: Horticulture	Mixed views on need for co-innovation	Very familiar with biopesticides History of working in this area Convinced of need for biopesticides	Focused on getting commercially viable products	Close association with industry to achieve outcomes Urgency based on need to meet market demands	More positive history with biopesticides 'Mainly focussed on the product and how that gets commercialised to farmers in a cost-effective way'	Strong focus on getting wider stakeholder group involved
Arable	Mixed views on need for co-innovation	Focused on project specific tasks, e.g. identifying farmers to trial biopesticide options Convinced of need for biopesticides	Need for a champion of this area	Need to develop relationships with new industry partners		
Pastoral	Mixed views on need for co-innovation	Need to expand team and so need to develop relationships with new industry partners Convinced of need for biopesticides 'Real innovation happens at the project level… collaborative bunch who are working together well'	Competing with other projects perceived as just as worthwhile for funding and attention	Worried about commercial realities and difficulties with getting biopesticides produced and to market	No urgent need for biopesticide solutions	

NGB: Next Generation Biopesticide programme; AIS: Agricultural Innovation System.

Secondly all organisations had to sign contracts and confidentiality agreements around the sharing of data and results, in order to protect IP and further commercialisation of the research outcomes. An interviewee commented: 'Trust between other programme partners is also good, but [I am] aware of confidentiality agreements'. Another said: 'Worried about 'free-riders' if the information is provided widely' [outside programme group].

Moreover, there were differing levels of support across organisations for co-innovation. For some the extra time and expense involved was not seen to have a positive impact on the aim of the programme. There was also a concern that '[we are] trying to do more than we can afford [because of a complex programme with multiple stakeholders]'. An industry partner clearly stated that for the research that they were funding a co-innovation approach was not necessary, as the uptake and adoption of the biopesticide would happen automatically when farmers could see the benefits for that particular product. Researchers recognised the need to involve leadership within the individual organisations to meet all of the NGB programmes goals (including co-innovation), but felt that they were not necessarily supported by their own organisation.

NGB programme

The fourth institutional dimension is focused on NGB programme outcomes, i.e. effective, usable biopesticides. Interviewees described the NGB programme goals as relating to uptake and use of biopesticides. They felt that it was important to have biopesticide development that met the needs of the New Zealand export market, as well as developing sustainable solutions for dealing with the range of pests that cause problems across different crops and pastures. Growing markets for New Zealand primary products through a clean green image (as exemplified by use of biopesticides) was critical and providing cost effective options to farmer through commercialised prototypes of biopesticides would help achieve this goal.

The biggest challenge for the NGB programme to achieve its outcomes has to do with the difference in perceptions of the programme between research and industry stakeholders. For industry stakeholders, there was quite a strong focus on their commercial goals for producing specific biopesticides. One interviewee's comments indicated they were: 'Mainly focussed on the product and how that gets commercialised to farmers in a cost-effective way'. In contrast, as mentioned above, the researchers were more interested in the fundamental research of developing biopesticides. In addition, there were differing levels of urgency for new biopesticides in each of the sectors, as well as differing levels of ease with which biopesticides could be integrated into the sector value chains. Due to all these differences between the stakeholders and their needs, the relationships between industry partners in the IAG were delicate, with a low level of trust.

In addition to fundamental research and commercialisation, the programme's success in terms of impact is dependent on the adoption and uptake of the biopesticides. Co-innovation was embedded in the programme to aid the development of fit-for-purpose biopesticides that would hence be more likely to be adopted. Although there was a general willingness to explore the use of the approach, there was a range of views on what co-innovation involved. All of the interviewees talked about a form of collaboration and engagement, but it was not clear to them who should be involved in this: 'involving a wide group of stakeholders, right from the start', for some this meant including end-users and getting feedback on the developed biopesticides, for others this was collaboration between researchers, building partnerships, and sharing data and results. On top of that, co-innovation also requires looking beyond the separate parts of a programme and connecting the parts together and placing them in a bigger picture. The narrow focus of researchers hampered this process. Co-innovation therefore involved a delicate balance between this need for more open collaboration, and the commercial realities of protecting IP to get a biopesticide to market. The earlier mentioned time and effort that co-innovation requires were also carefully considered, because of the perception of taking funding away from the research.

Biopesticide history dimension

The projects and other activities within each sector related to biopesticides prior to commencement of the NGB programme form the fifth institutional dimension. This dimension had an impact on co-innovation because of past successes and failures. One example of this was a researcher being sceptical about the success of the programme: 'Biopesticides have been around for a long time and have never really been used by farmers, so why would it work now?'. Previous experiences with poor performing biopesticides in the pastoral sector created reluctance for stakeholders (both on and off farm) in the wider innovation system to be involved. There had also been less successful collaborations in projects in the past, that fed into concerns about 'free-riders' (mentioned above) and created tensions between the industry partners who were involved

initially, but had left, and those who continued to be involved or who may be bought into the programme later. The horticulture sector contrasted with the other two sectors, as there was more agreement about the need for biopesticides and focus on route to market because product development was more advanced, and successful efforts in the past led to a more positive attitude regarding the NGB programme. The reason for this higher level of agreement was because of the urgency due to the widespread damage to kiwifruit orchards caused by the Psa-v disease.

AIS dimension

The sixth dimension is the institutional environment for agriculture in New Zealand. One major issue for the NGB programme, and especially the industry partners, was dealing with regulatory issues. As with chemical pesticides, biopesticides must be registered for use in New Zealand and this is a complex process in itself. One interviewee described this as a need for a 'brokering role' with regulatory organisations in order to help make the requirements clearer.

The other issue is the identification of research investors and commercialisation partners. Due to the two investors leaving at the start of the programme, it was necessary for the pastoral sector to identify investors from outside usual pool. Besides this lack of potential investors, there seems to be limited capacity and capability within the innovation system to upscale and manufacture biopesticides, and to develop routes to market. One person commented: 'Can we identify 'angel investors' outside the field who would be willing to take the risk [to invest in biopesticide production]?' They also felt there could be opportunities for funding with overseas investors or other New Zealand sectors, such as the food or public health sectors.

This challenge of finding additional investors and commercialisation partners is related to the earlier mentioned lack of support within the research organisations for the development of biopesticides and the co-innovation approach. There is a need for advocates and brokers for biopesticides within the agricultural innovation system, and more awareness needs to be raised of the potential for on- and off-farm benefits of biopesticides. This would help identify further potential investors and commercialisation partners. The horticulture sector tried to develop this awareness by getting a wider group of stakeholders involved through other funding opportunities such as Sustainable Farming Fund and Kiwinet. However, this was seen by researchers primarily as a means of obtaining more funding, rather than a focus on co-innovation.

Discussion

The results show differences between sectors in their perception of the programme and the use of co-innovation for a number of reasons. Firstly, because of the (lack of) support within research organisations for co-innovation. Hence more organisational support for the implementation of co-innovation in the programme is required, to realise benefits from the required time, effort and budget that the implementation of co-innovation takes (Botha et al. 2014; Botha et al. 2015). Secondly, there were differing levels of urgency for new biopesticide solutions in each sector. The horticulture sector seemed more open towards a co-innovation approach, or at least the involvement of a wider group of stakeholders, due to the crisis around Psa-V in kiwifruit (see also Park et al. 2015) and an integrated value chain (Turner et al. 2016). Thirdly, there were concerns over ownership of IP and technologies by stakeholders. The industry partners did not feel comfortable with co-innovation, collaboration, and hence sharing information, as it may attract free-riders and stand in the way of commercialisation. This was also linked to the fourth reason for differing perceptions of co-innovation: the level of ease with which biopesticides integrate into sector value chains.

These institutional barriers and enablers to co-innovation in the NGB programme are not uncommon to programmes trying to implement a co-innovation approach. Pinxterhuis et al. (in press) and Vereijssen et al. (2017a) describe similar issues with the lack of funding; the formation of networks and the inclusion of different types of actors, the lack of (willingness to) understanding of co-innovation and the role of historic events. Although as common as these barriers are, it seems that there is no recipe or a 'one-size-fits-all' solution to these kinds of barriers (Rijswijk et al. 2015; Fielke et al. 2017).

What connects all the above-mentioned barriers and enablers was that co-innovation in the NGB programme was most often perceived as collaboration only. This was mainly collaboration within the research team rather than with a wider group of stakeholders. Generally, co-innovation was perceived by the researchers as interesting but complicated. They didn't feel equipped to undertake co-innovation and were worried about it distracting them from their science, or worse, that co-innovation was using funding that was (or should have been) allocated to science. The use of programme logics was helpful in overcoming this narrow view of co-innovation (see also Vereijssen et al. 2017b) as it requires articulation of the steps from science output to adoption and outcomes, and the actors needed to implement these steps (Allen, Cruz & Warburton 2017).

The framework of Klerkx et al. (2017) has proven to give good insights about the individual to AIS-level institutional barriers and enablers to co-innovation in the NGB programme. It showed that the framework is useful for programmes that aim to implement co-innovation, especially to understand the different institutional levels and dimensions as influences on stakeholder behaviour, such as historic processes, the organisational support, or people's personal beliefs. For programme leaders, stakeholders and facilitators, it would be useful to have the framework translated in to a tool with guiding steps or questions for identifying the institutional enablers and barriers to co-innovation. The gained insights can give direction for future activities in the programme, enhancing the innovation process, however, they should always be considered in relation to the other structural elements of the AIS (the relevant actors, their interactions and the supporting infrastructures).

Conclusion

The NGB programme was designed with the complexity of developing and implementing biopesticides in mind, making use of co-innovation to ensure that co-development of knowledge was possible; technological, social and institutional change were enabled; and that new ways of working could emerge. The programme had a strong science and commercialisation focus with which co-innovation was intended to be integrated.

The institutional levels and dimensions framework (Table 1) was used to evaluate the institutional barriers and enablers to co-innovation from the point of view of the different stakeholders involved in the NGB program. The results showed differences between sectors in their perception of the programme and the use of co-innovation. The interviewees described the following institutional enablers and barriers that they encountered: i) institutional incentives for co-innovation within research organisations; ii) ownership of IP and technologies by stakeholders; iii) differing levels of urgency for new biopesticide solutions in each sectoral innovation system; and iv) the level of ease with which biopesticides integrate into the sector value chains.

Each of these aspects can either be a barrier to or an enabler for co-innovation. For example, when there are institutional incentives (enabler), no concerns over ownership (enabler), challenges with the uptake of biopesticides (enabler) and there is a high sense of urgency (enabler), then the different stakeholders and subsequently the related projects are more inclined to take on a co-innovation approach. From the interviews it became clear that all of these enablers, in case of the NGB programme, seemed to be largely absent or instead were a barrier to co-innovation. Hence there was little willingness to trust or try the co-innovation approach, both the industry partners and the research team felt more comfortable with the formally established level of collaboration.

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