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Abstract: Mango in Ghana is targeted as the next non-traditional export crop that is expected to fetch the highest foreign exchange for the country than cocoa. However, production and export constraints caused by fruit fly *Bactrocera invadens* has placed serious limitation on its marketing to the extent of imposing bans on imports from Ghana. Notwithstanding efforts rolled out to control the flies, they are still prevalent in the system. This paper presents the cost benefit assessments of using "Biotechnology and Nuclear Agriculture Research Institute (BNARI) protein bait" to control fruit fly *Bactrocera invadens* relative to other control measures in the Eastern region of South Ghana. Scientists from the BNARI of the Ghana Atomic Energy Commission developed a research programme against this foe. Cost benefit assessment revealed that chemical control reduce losses from 60% to 40% at the beginning of the growing season and can reach up to 60% for late maturing varieties at a cost of US$915.2 per acre per year. However, with the BNARI trap, losses are reduced from 60% to 5% at the beginning of the growing season and can reach up to 10% for later maturing varieties at a cost of US$688 per acre per year. Using BNARI protein baits to control fruit fly also provide growers with benefits such as improved quality and shelf life for fruit because it is not subject to chemical treatments. The casual loop diagram (CLD) revealed that fly control with BNARI trap is friendly to beneficial insects during pollination and has no harmful impact on health compared to the traditional approaches.

Key words: *Bactrocera invadens*, BNARI protein bait, export market, cost-benefit analysis, systemic mango value chain.

1. Introduction

Globally, the production of mango currently stands at about 50 million tons of fresh fruits and 290,000 tons processed mango pulp, puree and juice. Of this, Africa produces only five million tons, accounting for about 10% of fresh fruits and 11% of processed mango [1]. Ghana's current production is said to have increased from about 2,400 tons in 2007 to about 4,000 tons in 2008 [1]. Meanwhile, the demand for mango in Ghana far exceeds the supply [2]. Mango is one of the most important horticultural cash crops both for domestic and export markets with considerable potential of foreign exchange and employment [3]. Mango, which is one of the main traditional fruits, is also in high demand by local food processing industries. It is used for jams, dried fruits, flavours, juice, etc. [4]. Varieties of mango cultivated in Ghana include Keitt, Kent, Palmer, Haden, Tommy Atkins and Irvin. Mango in Ghana is targeted as the next non-traditional export crop that is expected to fetch the highest foreign exchange for the country and replace cocoa [5]. However, production and export challenges caused by the black fly (which was discovered in 2005), have placed serious limitations on marketing to the extent of imposing bans on imports from Ghana [2]. The fruit fly *Bactrocera*

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invadens, previously unknown in Africa, is seriously threatening fruit production, and especially the mango sector. This Asian species has rapidly spread throughout the continent where it has no natural enemies and is causing serious damage [6]. The Mediterranean fruit-fly, *Ceratitisca pitata*, is also one of the most destructive fruit pests [7]. These destructive flies infest fruits like mango, pawpaw, cashew, garden eggs and watermelon among others. Studies have revealed that the species originated in sub-Saharan African.

Exported mango containers are often rejected at the entry ports of the international markets due to fruit fly infestation and other sanitary issues [8, 9]. The international mango market community, which includes Europe, South Africa and the United States, has branded the West Africa region as a fruit fly endemic zone, and thereby refuse to patronise mangoes from countries in the zone including Ghana [10, 11]. Mangoes attacked by the pest are unfit for sale on either local or regional markets and are mostly burnt or buried to destroy to minimise infestation. Any infected fruit must be scrupulously removed. Failure to do so means the destruction of the entire batch on arrival in the European Union (EU) and a minimum charge of 31,000 Euro per container for the exporter [12]. Given the scale of the economic threat, the main actors in the fruit and vegetable sector have called for a common regional strategy involving all public and private stakeholders, to reduce the impact of these pests.

The West African Fruit Fly Initiative (WAFFI), jointly financed by the World Bank, the European Union and the World Trade Organisation (WTO), has piloted fruit fly surveillance and mitigation protocols in seven countries including Ghana since 2008 [13]. Notwithstanding efforts rolled out to control the flies, the fruit flies are still prevalent in the system. The situation continues to deprive mango farmers in Ghana of access to international mango markets, in spite of advocates and individual huge cost incurred in combating the fly. A range of control strategies attempting to address many of the constraints has had little success. Strategies to tackle the fruit fly problems include collecting and destroying fallen and infected fruits, putting them in black airtight bags and placing them in the sun so the larvae die from the heat, and monitoring other host plants (avocado, citrus) growing nearby. The battle against *Bactrocera invadens* will be long and difficult, for almost nothing is known so far about the pest's ecology and behaviour as well as their control is not cooperated among surrounding mango producers.

Scientists from the Biotechnology and Nuclear Agriculture Research Institute (BNARI) of the Ghana Atomic Energy Commission developed a research programme against this foe through the use of formulated protein bait. Therefore, this paper presents the benefit cost assessments of this program among mango producers in the Manya Krobo District of Eastern Region of South Ghana. Fig. 1 shows a distressed farmer involved in the study.

2. Materials and Methods

Protein baits traps were the main materials used in this experiment. The protein baits or pheromone traps as shown in the Figs. 1 and 2 were made from plastics containers bought on the Ghanaian market. The lures are compounds prepared from protein hydrolysis, methyl eugenol and insecticides. All compounds had supplier-reported purities of at least 98%. The lures were loaded in balls of cotton wool and placed in rubber container before being placed on the trees as shown in Fig. 2. The control bait was the hydrolyzed protein captor 300 prepared according to these commendations of the Radiation Entomology and Pest Management Centre (REPMC) of the Biotechnology and BNARI of Ghana. Both types of lures were changed every week for a period of nine months at the appearance of the first flowering.

Traps were placed at a height of 3 m (Fig. 4) close to the centre of the tree canopy at distances of

Fig. 1 Distressed farmer.

Fig. 2 Placing lures in containers.

Fig. 3 *Bactrocera invadens* fly.

Fig. 4 Placing traps on trees.

8-10 m apart and protected from direct sun exposure. All trials were arranged in a randomized complete-block design. Captured insects were removed from traps every seven days, after which traps were rotated within each block to reduce the effect of location. Trapped insects were placed in 20 mL flasks with 70% alcohol for preservation. The insects *Bactrocera invadens* as shown in Fig. 3 were identified and quantified in the laboratory.

This study was carried out in a 74 acre mango orchard in the Manya Krobo district. Mango is the major tree crop cultivated in the Manya Krobo district and a source of income for most of its inhabitants. The district has the biggest advantages in both ecological and economic potential that guarantee a dual harvest in a year in both the major and minor reasons. This is its huge competitive advantage for Ghana, since its climate allows dual harvest compared to other regions in the world. Land area under mango cultivation continues to increase every year. In 2010, a total area of 3,249.2 acres was recorded. Some of the varieties under cultivation include Keitt, Kent, Palmer, Tommy Aikinns, Harden, Erwin, etc. Mango growers in the district have received enormous training from Ministry of Food and Agriculture (MOFA) and other institutions like the Adventist Development and Relief Agency (ADRA), and the Trade and Investment Program for a Competitive Export Economy (TIPCEE) in the past.

Data was collected using stratified questionnaire and data analyses were based on a cost-benefit analysis and the use of the casual loop diagram (CLD) using software of Ventana Systems UK [14]. In the benefit-cost analysis, counterfactual situations were used to compare the benefits and costs of the changed situation. The counterfactuals used here are the "do nothing" case—that is, farmers who do nothing to control the fruit fly and those who used chemicals at the same community. In the “do nothing” case, yield loss as a result of fruit fly attack (endemic) was recorded. If all areas become infested, then growers are assumed to apply pre-harvest chemicals to control infestations to maintain market access. Post-harvest control costs are assumed to ensure fruit produce can be sold to sensitive markets. In the “do nothing” situation, growers do not have access to sensitive local and international markets. The benefits quantified in this benefit-cost analysis are the avoidance of pre or post-harvest chemical costs and access to the markets. The quantified costs are chemical and the use of protein bait costs following outbreaks. Area-wide management programs using BNARI protein baits to control fruit fly provide growers with a lot of benefits. These benefits apply to all management options. Their omission thus means this benefit-cost analysis underestimates the net benefits of all management options.

This analysis accounts for benefits and costs to growers and the wider community. In the case of environmental impacts, the study relied on the CLD to help producers or stakeholders to anticipate the long-term consequences of their decisions and actions, as well as help to avoid any unintended consequences of policies and strategies that may have any detrimental impact on local insects and ecological systems. This technique was used to determine the options that provide the best approach for the adoption and practice in terms of benefits in yield, labour, time and cost savings.

3. Results and Discussions

Mango takes about four years of which the average yield per acre is about 12 tons if it is a well maintained farm [15-18]. From seven years upwards, a well-managed mango plantation will yield an average of 10-12 tons per acre [18]. Harvesting mangoes is done in both the major and minor seasons [19]. Major harvesting is done in May-to-July and minor December-to-February [20]. According to the producers, the major local buyers of mangoes in Ghana include the wholesalers and retailers in the local markets, supermarkets, hotels and some processing companies. However, there are also a sizable number of exporters who rely on these producers to provide the bulk of their export.

The allocation of existing resources and the management of costs to derive future benefits such as access to sensitive markets for mango production are key responsibilities of mango producers in the study area. Mango farmers face complex decisions and as a consequence, the management process has become more difficult, requiring greater skills in planning, analysis and control. Table 1 presents the revenues a farmer may obtained in mango production based on management choice and activities.

3.1 Ex-ante Analyses of Impact of Fruit Flies on Farmer’s Income

Mango harvest losses as a result of *Bactrocera invadens* are held down to 60% at the beginning of the

Table 1 Estimated revenue from one acre mango production.

Element	Year 4	Year 5	Year 6	Year 7
Number of mango trees per acre	40	40	40	40
Yield of fruits per acre (tons)	6	8	10	12
Price (US$)/1 kg of mango fruit	0.28	0.28	0.28	0.28
Revenue (US$)/acre/year	3,360	4,480	5,600	6,720
Number of fruits left without flies control	1,500	2,000	2,500	3,000
Expected revenue (US$)/year	840	1,120	1,400	1,680
Number of fruits with chemical control	3,360	4,480	5,600	6,720
Expected revenue (US$)/year	1,882	2,509	3,136	3,763
Number of fruits with protein bait control	5,550	7,400	9,250	11,100
Expected revenue (US$)/year	3,108	4,144	5,180	6,216

growing season and can reach 95% by the end of the season [21]. Beside the direct damage to fruits, indirect losses are associated with quarantine restrictions on sensitive markets. According to mango producers in the study area, despite the importance of mangos in the dietary and nutritional needs of the people, farmers faced between 60% and 95% harvest losses in their investment due to invasion of fruit flies that had become a major threat to the thriving industry.

Farmers are losing the fight largely because the fruit fly has a wide range of hosts and it also migrates across mango plantations in the sub-region [22]. The females lay their eggs under the surface of the fruit skin as shown in Fig. 5 [23]. After hatching, the maggots penetrate the flesh and destroy the fruit from inside as shown in Fig. 6 [23]. They have an incubation period of 2-3 days with fecundity range of 10-21 days and pre-ovipositional period of 1.5-2.5 days [24]. Larvae will complete their growth cycle in the soil as infested fruit fall from the trees to the ground and create outbreak sites.

3.2 Traditional Control Measures

Farmers go round the orchard to quickly remove infested fruit or pick up dropped fruit every day to destroy by burying fruit in a pit (4-6 m deep), to allow for decomposition with the resulting heat destroying larvae as shown in Figs. 7 and 8. Others collect infested fruit in an impermeable plastic bag and exposed them to the sun to kill larvae. Some also burn fruit in a ditch or a tank. While others weed carefully around the trees to makes it easy to see and pick up fallen fruit.

Fig. 5 Mango infested with eggs under surface.

Fig. 6 Fruits penetrated by maggot.

Fig. 7 Buried mangoes in a pit.

Fig. 8 Pit covered to retain heat.

As a matter of urgency, farmer also do mass spraying programme for their mangoes. Prior to insecticide treatment, it is important for farmers to decide on the application method depending on flowering stage. Most farmers prefer the use of knapsack during the early flowering stage to prevent abortion while others use the carried-sprayer with a centrifugal pump to ensure homogeneous distribution of the chemicals on all parts of the tree.

Insecticides such as super dam and cydem super with active ingredient-demetrio are sprayed with knapsack or carried-sprayer with a centrifugal pump twice a week from flowering stages until two weeks before harvesting. Most farmers prefer to use the carried-sprayer with a centrifugal pump to spray insecticide because of its wide impact [25]. According to farmers, this approach kills beneficial insects helping with pollination in the mango plantation there reducing yield on the average by 20%. The total cost of chemical control of fruit flies as shown in Table 2. Chemical control to treat an acre of mango plantation ranges from US$688 to US$915.2 for the two harvesting seasons per year depending on the mode of spraying.

According to farmers, chemical control reduce losses from 60% to 40% at the beginning of the growing season and can reach up to 60% for later maturing varieties. According to farmers, not all surrounding mango farm follow control practices and this pest migrate and re-infest their plantations from adjacent infested farms.

3.3 Impact of BNARI Trap

A protein baits traps developed by BNARI, also known as BNARI trap are used to capture male flies *Bactrocera invaden*. At present, they are the most effective and efficient way of controlling these fruit flies. When used on time in mango plantations, it can hold down the fruit flies population growth early in the season [26]. BNARI traps are installed at the beginning of mango flowering impregnated with a specific pheromone lures treated with a contact insecticide. Small balls of cotton wool are soaked with the pheromone solution containing the insecticides to attract the male *Bactrocera invaden*. This cotton is then placed in the BNARI trap with a strip that allows it to be hanged on the trunk of the mango tree. The trap has been designed in such a way that it is not affected by rainfall. The cotton wool is renewed every seven days, till all fruits are harvested. This type of treatment has no effect on the orchard's beneficial insects, and no risks for farm operators and consumers compared to the heavy dose of continual chemical treatment.

The cost per set of trap for the two fruiting seasons, activated every week for a period of 36 weeks (nine months) was US$17.2, making the total needed per acre of mango field amounting to US$688 per year. According to farmers, the use of BNARI trap reduced losses from 60% to 5% at the beginning of the growing season and can reach up to 10% for later maturing varieties. Fig. 9 shows trapped and dead *Bactrocera invaden* with BNARI trap. Fig. 10 shows a beneficial farmer giving data to scientist on BNARI trap impact. Farmers are very happy with this mode of control and know that it is a solution to the threat of the mango export market.

Using BNARI protein baits to control fruit fly provide

Table 2 Cost of chemical control of fruit flies.

Input description	Unit cost per acre (US$)	Quantity demanded per one season	Total cost per acre (US$)
Superdam or cydem super	21.5	8	172
Spraying			
a-Knapsack	21.5	8	172
b-Blower	35.7	8	285.6
			With Knapsack-344
			With Blower-457.6

Fig. 9 Trapped *Bactrocera invaden*.

Fig. 10 Farmer expressing lost impact.

growers with benefits that this study has not quantified, such as:

- Improved quality and shelf life for fruit because it is not subject to chemical treatments;
- The increased viability of integrated pest management systems due to less chemical use;
- Access to sensitive markets without incurring pre harvest chemical costs and post-harvest chemical (disinfestation) costs;
- Fruit fly controlled with BNARI trap also has no human health impact.

3.4 The Systemic Mango Value Chain

Fig. 11 presents the CLD of the socio-economic activity and mango management systems among the farmers of Manya Krobo district. The purpose of this model is to give understanding of the direct and indirect feedback loops between socio-economic or farm management activities and its impacts on mango value systems. This will allow producers to identify business opportunities that directly or indirectly improve productivity and support the development of sustainable and profitable business activity. The models can also be used in the development of decision support toolkits by producers and policy makers [27].

The CLD consist of variables connected by causal arrows with polarities such as: same "S" and opposite "O" signs to describe the causal linkages [28, 29]. Feedback loops describe the circles of cause and effect that take on a life of their own. Fig. 11 illustrates feedback loops of mango management regime exploring the success or failure of sustainability. The arrows links in Fig. 11 form feedback loops. This indicates that a given change kicks off a set of changes that cascade through other factors so as to either amplify ("reinforce" (R)) or push back against ("damp", "balance" (B)) the original change.

The diagram shows that the ability for mango producer to market his fruits is dependent on insect control and acquired knowledge through experience and training. However, insect control, training (MOFA) and effective and functioning research and development (R&D) all cost money. The good of optimising the ability to market mango fruits is therefore in direct conflict with the good of minimising cost. Rejections of produce from the market are not free, they incur cost in two ways: the cost of correcting the cause of rejection and the cost of losing market shares. However, if rejections increased, it put more strain on MOFA, and pressure on quality which in turn affects the ability to export and farmers get disaffection on mango production and exit the business. If the ability to market mango fruits increases, so would rejection diminished and so does cost. This will in turn increase sales revenue and profit, which will provide accessible funds for re-investment leading to increased farm sizes and economy of scale which is in opposite direction to cost increase. Ability to market will also increase ability to export which will bring in more foreign

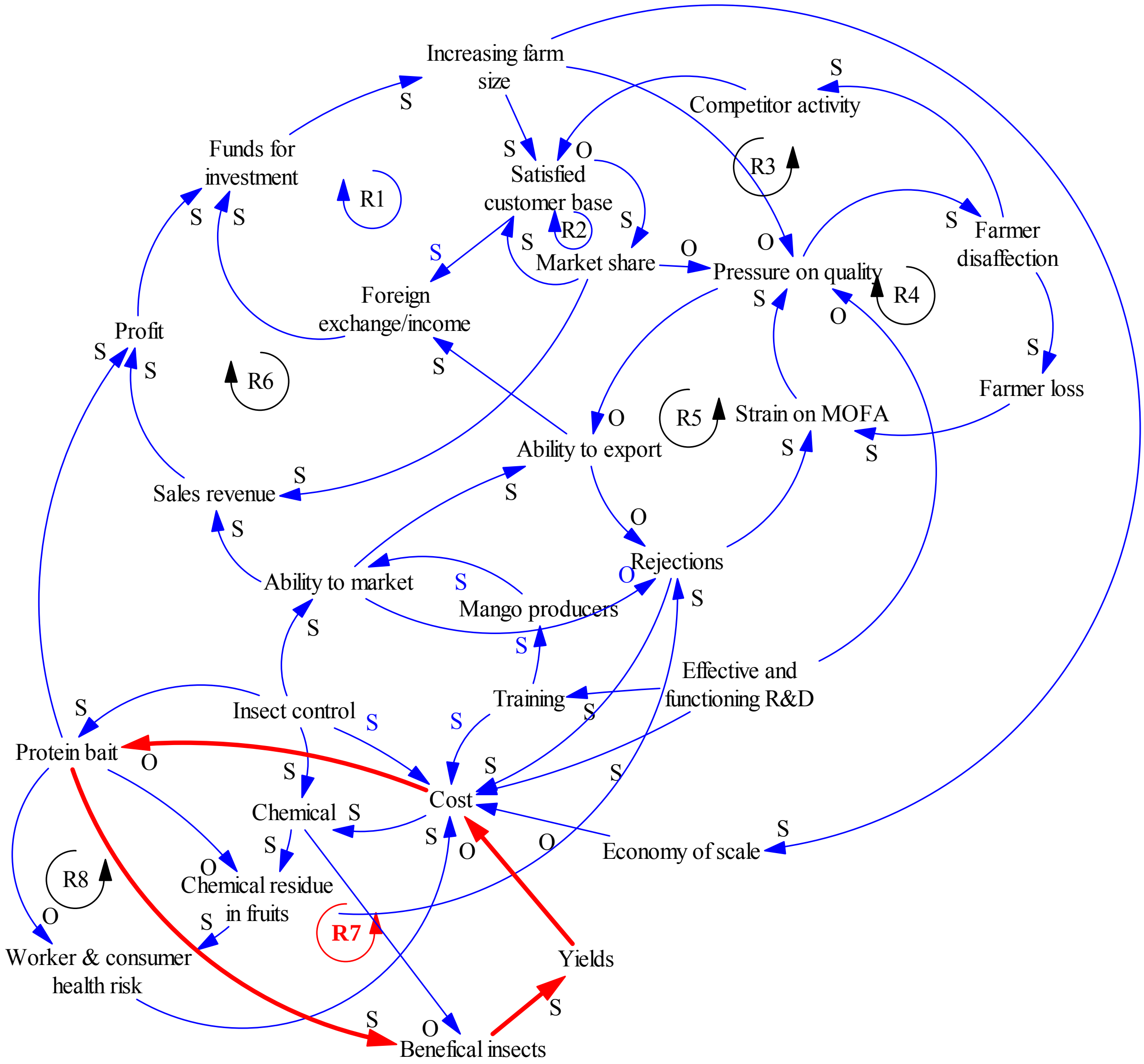

Fig. 11 The systemic mango value system.

exchange and provide funds for investment reducing export rejections. The signs O & S on the arrows have a special meaning, different from the usual one. The sign S means that a change in one variable has an effect in the same direction on the other. Thus an increase in the ability to market causes an increase in the ability to export (Fig. 11). And a decrease in one causes a decrease in the other. The sign O means that a change in one causes a change in the opposite direction in the other. So ability to market tends to reduce export rejection [28, 29]. Fig. 11 illustrates eight reinforcing loops (R1-R8). For example starting with the use of protein bait, and tracing the effect through all the elements of the loop (in the red color of Fig. 11). If a change in the original variable in the end causes an additional change of that same variable in the same direction, we call it a reinforcing loop (R) because it reinforces the original dynamic. More protein bait means more beneficial insects, which increases the mango yields and reduces cost even leading to more adoption of the protein bait (R7). A reinforcing loop tends to cause exponential growth in all variables in the loop. A positive reinforcement involves the addition of a reinforcing stimulus following a behaviour that makes it more likely that the behaviour will occur again in the future. Increasing farm sizes will lead to satisfied customer base which will lead to increase and security of market shares. Insect control which is the main factor influencing the ability to market is mainly dependent on chemical control which results in excessive residue in fruit and in the same direction of rejection. Chemical usage and residues also affect beneficial insects helping with mango pollination, thus reducing mango yield to 20% on the average. This also affects workers and consumers' health [21]. Fig. 11 shows that the use of the protein bait has no residual effect on fruits and health of both workers and consumers including beneficial insects.

4. Conclusions

The net benefit increased was very high from using the protein bait compared to alternative controlled measures. The use of protein bait increase the profit compared to that of the "do nothing" case and chemical control as depicted in Figs. 5 and 6. Results showed that farmers reap a minimum of 90% of their mango yield compared to 60% when chemicals are used. This is a tremendous improvement in the final fruits picked for the market by mango farmers. Also, farmers will be able to take over and use this trap without scientist from BNARI going every week to activate or renew the bait making it highly adoptable. All they will need is to purchase the formulated protein bait solution from BNARI. The economic and institutional condition favours the implementation of the BNARI trap at a national level to help save mango yield. Ghana has a comparative advantage in terms of good rainfall and soils to produce higher quality of the fruit to meet the growing international demands. Government is to exploit the potential of BNARI trap to help Ghana mango sector capture value and a fair share of its international market.

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