AI, FLIES, AND RASPBERRY PI

An interview with Sarah Nawoya

JONATHAN FEAKINS —— SARAH NAWOYA

To start with the shortest but possibly most complex question, what is your origin story? What led you to the intersection of both insect agriculture and computer vision?

I grew up in a rural area — the eastern part of Uganda, in a district called Kibuku — where most of our activities would be agriculture: you had to till the garden, from seven to eight, and then at eight you bathe and go to school. So this is something in my veins.

When I reached my bachelor's, I pursued a Bachelors in computer engineering, and I went on to do my masters in Internet of Things at University of Rwanda, leaning towards embedded computing systems. With this, we look at sensors, actuators, how to automate, how to make agriculture and health systems smarter.

I went to work a bit in industry, with a company called Innovex, assembling remote monitoring for solar systems. But I felt like I

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NOTE:
This interview has been edited for clarity and length.

needed to get back into research, because there was more to explore. Inside me, I felt a need to go back for a PhD, either AI in agriculture or AI in health. I thought I needed to do something to use technology in agriculture, and that is the way I would connect and give back to my community.

Then I got an opportunity for this FLYgene project, coming up with a sustainable feed for livestock production, looking at the Black Soldier Flies. We want to gain new knowledge of the Black Soldier Fly (BSF) genetics, genomics, and phenomics to inform the design of sustainable breeding programs in Kenya and Uganda. I saw that it fits directly to my needs and what I really want to research: developing a low-cost IoT system, and now computer vision/ deep learning for identification and the measurement of the traits of a black soldier fly in managed breeding sites. This was a project at Makerere University, and I did a visit to the center of Quantitative Genetics and Genomics (QGG), Aarhus University in Denmark and University of Nairobi in Kenya. That is how I got here.

> For those that aren't already familiar, can you explain why black soldier flies have received so much attention within the world of insect agriculture?

There are many insects for feed. We have the mealworms, we have the grasshoppers, and also the black soldier flies among others. But one of the reasons, I think, why the black soldier flies have received so much attention compared to these other insects is the low input. They grow very fast, so they're able to grow within three weeks — unlike the mealworm, which takes three months.

They decompose waste: pig manure, chicken manure, all these different things. So you get a circular bioeconomy: if it's a poultry farmer, the output from the poultry is fed to BSF, and then the chicken eats the BSF. If it's market waste, then we use this BSF to decompose this waste.

They also have different outputs. They produce frass, used as a fertilizer. Depending on what they have been fed, they have really high protein content. If someone is looking at substituting the fish meal they feed to their poultry, the BSF has a cheaper cost. They emit fewer greenhouse gasses. Also, their production can be done anywhere. Rural, urban: we have waste everywhere. And they really do not need a lot of water. So this really helps make BSF stand out.

> You're speaking right now from Kampala, where you're a PhD student at Makerere University. But you were also a Visiting Research Fellow at Aarhus University in Denmark, where you were one of five East African PhD students at their Center for Quantitative Genetics and Genomics' FLYgene project. What is this project?

We are coming up with more sustainable traits for the black soldier fly, to improve its efficiency for large scale production. For example, the chicken, in the 1950s, was really small with a slow growth rate. As selective breeding went on, people kept picking the bigger chicken.

So in the FLYgene project, we are looking at having a sustainable trait where we maximize on important traits such as size. I'm one of 4 PhD students on the project. I am looking at automating phenotyping, using computer vision and deep learning models, to aid in the selection of bigger and heavier larvae. This helps the farmer pick out the healthier ones.

The bigger the larvae, the more protein it has. So I set up a Raspberry Pi and a camera. I analyze the weight and size of these BSF and inform the farmer that if, for example, you have 100 trays, maybe tray numbers 50 and 51 are the biggest. A big larva gives a bigger fly, and the bigger fly translates to more eggs. On average, a black soldier fly gives 400 or 800 eggs. So this may increase the farmer's output at the end.

I'm also looking at this from the angle of being able to scale. Unlike big livestock - like cattle and chicken, where you can easily spot the big one with your eyes - these larvae present in large numbers, very small, and fragile. They also have a short life cycle. By the time you finish manually analyzing maybe 50 trays, they've molted to the pupae stage.

A lot of the biggest insect agricultural start-ups have been - apologizing for the pun - dropping like flies: Ynsect in France just collapsed, both Innovafeed and Protix canceled plans for new plants in the U.S., and the BSF samples in your most recent paper came from Denmark's ENORM, which declared bankruptcy this winter. What makes insect agriculture such a difficult industry? And how do you progress your own research, as the industry deals with these growing pains?

I actually got an opportunity to visit ENORM, when I was in Denmark. I really appreciated the work they were doing: it was a big investment, a lot of automation with the tray handling, and all that.

From my experience - and maybe a perspective from Africa, Uganda in particular - it is the cost of feed. In Europe, there's a lot of restrictions around using waste. The cheaper model would be using waste, but there are a lot of restrictions still in the EU with regard to the type of feed.

But on the other end, I think customers have not really embraced insect-based products. There has to be sensitization, and diversifying products that come out of insects: during my visit to Sanergy in Kenya, one of the BSF facilities, they make products such as insect based feed, BSF oil, and fertilizer production from the frass. And I've also seen research about the potential of BSF in the generation of biodiesel.

Another challenge in low resource environments like Uganda, there is a need to invest in low-cost environment monitoring systems. We depend so much on nature, which sometimes is not sustainable. Humidity and temperature are the most important environmental factors: for black soldier flies to thrive, they need temperatures around 27 to 30 degrees. Temperatures below 25, they will thrive, but they become dormant, they will not mate, their eating really slows down. And when the temperatures shoot beyond 30 to 35, they start dying. So the continuity in the colonies is hard.

In East Africa, places like Flyful Farms just opened their farm in Ruiru, and the IN-FEAST partnership just had their first stakeholder events and roadshows. When FLYgene first held workshops in Uganda and Kenya in 2022, they stressed the potential of BSF farming as a means of income for women and landless youth. How can this technology stand to benefit small-scale producers and rural farmers?

In East Africa, almost everyone - not everyone, but the largest percentage - have smartphones. So from this imaging station, how can we now deploy this model with the aid of an app? Everyone will be able to use their phone, create an account, and scan the different trays. Even if they're small-scale farmers or large-scale, this would really be an affordable solution for sustainable insect production. Right now, we're just working on a prototype: next week, I'll be deploying this at University of Nairobi.

In the East African context, insects-as-food is accepted as a cultural practice and long-standing tradition - there's nsenene, there's white ants, et cetera. What is it like to witness insect agriculture suddenly become a topic of global interest?

Here, it's a mix of opinions. I've had friends reach out: Hey Sarah, I want to do fish farming, but I also want to have a BSF facility to feed my fish. I see people piquing their interest.

Just the nature of the black soldier fly, the larvae itself - it's a bit "disgusting," in quotes, to other people. But the nsenene, it's become more cultural: they just come and fly, and some cultures do eat them, some do not. The same for the white ants: some people do eat them, and for some cultures it's taboo. But the insects as a food, it's been part of us.

Even BSF, some people approach it from a cultural angle. During the FLYgene workshop, we had farmers share their experiences from negative attitudes from neighbors who think you are "dirty" by rearing BSF. They say, "Oh, these maggots really feed on anything, they feed on human waste." Maybe people fear that if your customers know that you're feeding your chicken these dirty things, they will not support you.

From personal experience, I really liked the idea of working with these insects. But getting one-on-one with them - touching it, feeling the texture, counting the segments - it took my brain time. I also think about the language we use: if someone calls it a maggot, it's like something rotten, and belongs to the bin. But if someone calls it a larva, it's a bit more appealing.

How is BSF prepared for the animal feed? And if developed for human consumption, how much more does it have to be processed?

One way is giving them live to chickens for feed: you harvest larvae, and let the chickens eat them fresh. That is when they are around 12 weeks,with the highest level of protein and other nutrients. Another way is, dry them and mix them into different feeds to boost protein content. But we still need to standardize the BSF-as-feed preparation process, and to do some nutritional testing.

In Uganda, BSF has not yet been authorized for human consumption. However, mealworms are brushed into porridge for children, and the grasshoppers, crickets are really good here for human consumption.

In your paper from January 2024, you remarked that "In order to acquire accurate results, DL models require large and high-quality annotated datasets. However, there are few free-access annotated datasets related to insects for food and feed." How much does this lack of training data bottleneck development?

Because not everyone would have access to this BSF. To collect this dataset, you need to go through the entire breeding process. That's what I had to go through. And not every researcher would have the resources to get the eggs, set up a facility, and follow through.

For example, for the sex prediction data: I had to look at the larva, give it an ID, capture the image, wait for it to reach the fly stage where at last I can identify the sex, then trace back the ID to the image. The weight prediction dataset required weighing, manually, one larva at a time.

The availability of these datasets will enhance research in BSF. I posted my dataset online, and the last time I checked, two months back, I had I think close to 70-something downloads. So this shows that people are picking this up. They really want this data to be available.

So predicting sex larvae is important because maintaining a proper sex ratio can dramatically improve yields. In your most recent paper, you used a You-Only-Look-Once (YOLOv8) model for segmentation and detection, and then a ResNet model to predict sex three-quarters of the time - but you're then faced with the "black box" problem, where you're left uncertain what characteristics inform this prediction. How do you crack this box open?

We've tried looking at the model, and seeing where it is learning from with explainability methods. For example, If it shows that this is female detected, is it looking at the tail, the middle segment, or the head? One challenge we also had: our dataset was really small compared to the standards of deep learning and machine learning models. Also, different larvae fed on different feed may present slightly different body features: some may be more broad, maybe some more long. We need to diversify more. Such a dataset will really inform stronger results, because it has been tested in different environments.

If the explainability of the AI model can really point us to where to look, then we could now go back with the entomologist, and tell them, this is where we are looking, this is what the model is informing. Maybe now we could combine these two fields, to come up with something concrete.

The good news is that there is ongoing research by other researchers building on from that to drive further the sex prediction of the BSF sex, because research is a collective effort.

There've also been efforts to analyze nutritional content of BSF, most notably through NIRS (near-infrared spectroscopy) or FTIR (Fourier Transform Infrared Spectroscopy). Besides sheer mass or larval sex, what else might computer vision be able to tell us about BSF through imagery alone, and how?

The spectroscopy is being tackled more by my colleague, Frank [Ssemakula]. We collaborated on the review article: I contributed the computer vision part, and he's digging deeper into understanding protein content from these images, because it would help inform us which feed is the best. From these cameras, we can see if it is soya, maize bran, and all the others.

Other traits that can be seen with computer vision is behavior - and I think this would be pushed further, to the adult stage, to mating behavior. How are they interacting with one another? How are they picking their partners? If it's really laying eggs, and then how many eggs?

But also, to see the pests. We had a challenge here at Makerere one time: they were really small, but they infused themselves in the pupae. The pupae did not hatch - nothing. When you break them, you find a pest inside that attached itself to this larva during molting. If there is any pest invasion, it would inform this person to take action early.

Now, spectroscopy is an investment largely outside the reach of working farmers. So one of the products of your research has been your Raspberry Pi setup, between 100-200, which farmers could actually afford. So what have been the benefits and challenges of adopting IoT (Internet of Things) in the region, especially in relation to agriculture?

I first tried with a Pi 3, where I had challenges with loading the model, it was a bit slow, so I upgraded to a Pi 5. The more you upgrade, the higher the cost, but I just needed to see things working. But now we look at a lighter model on a lower-end Raspberry Pi, which is lower cost.

We see today more precision agriculture, where farmers get more information about what's happening in their farms. There are solutions that have been adopted, mostly for tracking cattle, where people attach tags to these cattles' ears, and they are able to track their herds and reduce theft. But not everyone can afford that, and not everyone is aware yet of the possibilities. So the need is to make this more low-cost - and to improve the coverage, the connectivity.

But I think the first thing that you need to assess is bias. I'll speak for my mother in the village: "This is how we've been doing this, and I don't see the need to do it differently." From my interaction with the farmers, they're like, "We are still able to operate." Maybe if these IoTs would help them get customers, to open more market - but also, if people hear of technology, what runs to their mind is: "I can't afford it. It's really expensive." So we need to spread knowledge that this is really low-cost, and in the long run, you'll be able to simplify the way you do things.

Where would you like your research to go next? What is your vision of insect farming?

First of all, to come up with a really low-cost solution able to run on a phone with a lighter model. The YOLOv8 I'm running is 23 MBs - and I've added in things like scanning the ID of each tray. What helps me to read the trays is the OCR, which is also a bit heavy. So I look at finding ways of really making this run on a low-cost device, and moving to test it with the community.

There is what we want in the lab, but also what people want in the field. Like an advisory tool: if you want to do 50 grams of larvae, then add a half kilo of maize bran, add this and that. The farmers really need some tool to help them to come up with this nutritional composition.

And finally, is there anything that I did not ask, but I probably should have?

I would like to give a shout out to L'Oréal-UNESCO for Women in Science: for the training that we had, their support of my PhD and the FLYgene project, and to be able to speak to you with confidence. Because initially, I think I would have thought: "Is this a scam? Why would anyone want to talk to me?"

That just means that people need to talk to you more!