Children with konzo as a result of toxins produced in their food. Faces have been blurred.
Photo: Julie Cliff

Food Security in a Warming World

BY ROS GLEADOW

Increasing levels of atmospheric CO2 will change the nutritional value of food for both people and livestock – and even lead to higher levels of toxic cyanide in some staple foods and pastures.

Double the food with half the resources by 2050 – that is what we need to aim for if we are to provide food security for all 8.5 billion people. Climate change will make the job harder, with droughts and floods leading to poor yields.

But another challenge is yet to make it onto the radar screen. Rising carbon dioxide levels will almost certainly decrease the nutritional value of most staples, and some are set to become more toxic as well.

Rising carbon dioxide levels should boost plant growth and crop yields. After all, carbon dioxide is the key raw ingredient that plants use, together with water, to make carbohydrates.

But the chemical composition of plant tissue can also change, and not for the better. The protein content of cereals such as wheat and rice, for example, is likely to decrease by 10–15% in the coming century, and may have already decreased as a result of atmospheric changes during the past century. That's not a problem for those of us who eat a bit of meat, but if you are relying on grains or legumes it is a big problem.

As well as protein and carbohydrate, plants contain all sorts of other chemicals. These act to protect them from herbivores and pests. Some easily recognised examples are vanilla, cinnamon, nicotine, caffeine and ones that taste like marzipan. Our ability to tolerate these natural toxins depends on the amount eaten at one time, and the amount of protein we ingest.

Experiments have shown that the leaves of plants contain higher concentrations of phenolic compounds (the cinnamon-type ones) when grown in an atmosphere containing about twice today's level of carbon dioxide. Together with lower protein levels, this could mean that koalas and other marsupials will no longer be able to survive on gum leaves.

No one really knows what the effect of lower protein and higher defence chemicals will be on sheep and cattle. We did one experiment where we grew clover, an important pasture plant in Australia, under different carbon dioxide emission scenarios. Clover contains cyanogens that break down to release toxic cyanide gas when mixed with a specific enzyme. The plant stores the cyanogens separately from the enzyme so that it doesn't poison itself, but when an animal comes along and chews it, the two are mixed together and the cyanide is released – much like an organic cyanide capsule.

Cyanogens are quite common in food plants, and animals can readily detoxify cyanide as long as they don't eat too much as once and also digest plenty of protein.

In our study on clover we found that there was only a small increase in the cyanogen content when we grew plants in the sort of atmosphere we will have in about 50 years time (700 ppm CO_2). However, its toxicity nearly doubled because the amount of leaf protein available was much lower. As a result, this type of clover may end up being unsuitable for grazing in the not-too-distant future.

There are, however, alternative varieties that do not make cyanogens, so there is a solution. This research demonstrates that we need to do the research now in order to plan for the future.

The reason behind the changes in leaf composition is really an economics argument. Photosynthesis is the process whereby CO_2 is converted to chemical energy (sugars) using solar energy (sunlight) and water. The efficiency of this process improves when plants are exposed to higher concentrations of CO_2, resulting in readjustments in the relative inputs and outputs at many levels.

One advantage for the plant is that higher CO_2 levels reduce the amount of photosynthetic enzyme required to power the whole process. Since most leaf protein is actually photosynthetic enzyme, any reduction in that one enzyme affects the overall protein content of the leaves. Any animal eating the pasture, such as a cow, will consume less protein per mouthful.

Moreover, in crops like wheat there is less protein available at the end of the growing season to be redistributed to the ripening grains, so they have less protein in them as well. Resources that might have gone towards photosynthesis are instead allocated to defence chemicals such as phenolics or cyanogens. This is good for the plants, but bad for the animals that eat them.

While anti-nutritional factors are not normally a problem in human food, some are, and it is important to know what will happen under future climate scenarios. Another crop we have studied is cassava. This plant is scarcely known in Australia but it is the staple food for 750 million people in Africa, Asia and Latin America. In fact, it is the third most important source of calories for people in the tropics and the most important crop in sub-Saharan Africa.

Cassava tubers look a bit like sweet potatoes and are almost pure starch. This makes it a great source of carbohydrates, but not protein or vitamins. It is sometimes called the "drought, war and famine" crop of the developing world because it grows fast on poor soils with little water, and requires relatively little cultivation. It may even be something that we could grow in drought-ravaged Australia.

The rub is that this plant contains toxic cyanogens. If not correctly prepared, cassava can make you sick or kill you. Too much cyanide and insufficient protein in the diet can lead to outbreaks of paralysing diseases like tropical ataxic neuropathy (TAN) and the more severe konzo. TAN is the result of eating slightly too much cyanogen over the long term, and is mostly seen in older people. Konzo is the result of ingesting high concentrations of cyanogens over a short time interval, causing irreversible paralysis of the legs or even death. Children and pregnant women are particularly at risk. Konzo is widespread and persistent in southern and eastern Africa, particularly in times of drought, war and social upheaval.

It is usually the women who process the cassava. Most of the cyanogens are in the peel of the tubers, so that is removed first. Then they are chopped or grated and either sun-dried, soaked or fermented before being pounded into flour. Processing can involve a combination of these methods and can take up to a week before the flour is ready for consumption.

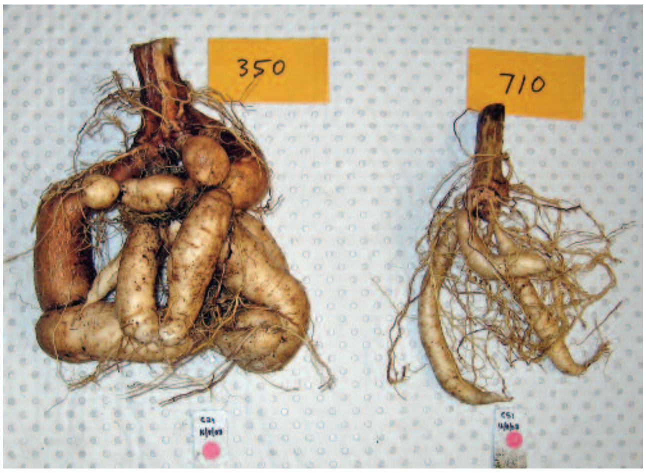
Sun drying and heap fermentation remove 60–85 % of the cyanogens in the tubers, but grating removes 97–99%. Grating is particularly effective as it mixes the cyanogens with the enzymes in the tubers, but it is very time-consuming. However, the final amount of cyanide in the flour depends on the initial levels of cyanide compounds in the cassava plants.

You may ask: "Why not produce less toxic varieties of cassava?". In fact they do exist, and are universal in the Pacific Islands, but there are many social and agronomic reasons why they have not been embraced in southern Africa. Not least of these is that the need for processing the tubers keeps the food chain in the hands of the women, and less likely to be pilfered.

Dr Howard Bradbury of the Australian National University (ANU) has developed a new method of processing cassava flour that further reduces cyanide concentrations, and this method is gradually being adopted even though it requires a change in domestic practices.

The World Health Organisation's limit for cyanide in food is 10 ppm, but this is often exceeded in parts of Africa. In the early 1990s Bradbury and Dr Julie Cliff, a medical doctor residing in Mozambique, sampled flour in marketplaces in northern Mozambique and measured the cyanogen levels. They found that in a normal year the flour contained, on average, 45 ppm cyanide but in a drought year the flour had more like 100–200 ppm!

This explains why outbreaks of konzo coincide with droughts. Drought-stricken plants reallocate resources away from photosynthesis to defence, and hence become more toxic. In addition, there is



Cassava tubers of plants grown at elevated carbon dioxide levels (right) were about half the size of those grown in today's air.

Source: Gleadow *et al.* 2009, *Plant Biology* 11, (Suppl.1) 76–82. Photo: John Evans

a greater reliance on cassava, less protein sources and sometimes less opportunities for processing as well. The result is a toxic mix.

With global environmental change, Mozambique is expected to become drier with more extreme weather events such as drought. This is not good news for the people who eat cassava.

When I read of Bradbury and Cliff's research I wondered if the cyanogen content would increase with CO_2, like we found for clover. I went to Canberra with my colleague, Tim Cavagnaro, to grow cassava at the ANU's Research School of Biological Sciences, where Bradbury was getting some plants ready for me. Together with John Evans we grew the plants at three different emission scenarios: today's air (controls), and air with one-and-a-half times (560 ppm) and approximately twice (720 ppm) the concentration of carbon dioxide as today's air. This represents the sorts of levels we can expect in about 20 and 50 years time, respectively, given the current worst-case scenario for carbon emissions.

The results gave some good news and some bad news. The good news was that the starchy core of the tubers did not show any increase in cyanogen levels. The peel was more toxic, but that is always removed, so overall the tubers will not become more toxic as a result of carbon dioxide alone. In fact, the higher cyanogen levels in the peel might make them more resistant to pests.

The bad news was that the leaves were significantly more toxic, with a much higher proportion of cyanogens compared to leaf protein. But people don't eat the leaves that much, and in Mozambique they are usually well-processed. On the other hand, people do eat the leaves as a salad in Indonesia and Brazil, which might not be such a good idea in the future. So while the increased toxicity of the leaves is a worry, it is something that can be managed.

But food toxicity is only one of the effects of CO_2. More worryingly, we found that the cassava plants in our elevated CO_2 glasshouses did not grow as well. In fact, the tuber mass

Cassava flour needs to be prepared carefully to remove cyanide toxins.

Photo: Natalie O'Donnell

of plants was reduced by more than half in one of the nutrient treatments. That is a massive decrease. If this occurred across the world there would be widespread starvation, which would inevitably lead to social dislocation and political unrest.

We don't really know why cassava responded to the higher concentration of atmospheric CO_2 in this way but we saw the same thing in two different cultivars grown and at two different fertiliser regimes, so it seems pretty real. There are some suggestions in the scientific literature that potatoes might behave in a similar way.

No one knows the answer to that question yet, but if all root crops reduce their growth like this then food security will be jeopardised in a big way. I just hope we are wrong.

According to the United Nations, food security exists "when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". Any erosion on the nutritional value of staple crops would therefore decrease food security.

There is no doubt that grains and leaves will have less protein in them under future atmospheric conditions. Many plants will also produce more of the natural chemicals that defend them against herbivores. This poses a very real threat to food security.

This is not just a climate change issue. It is a direct effect of our changing atmosphere. I would love to be able to say that we will just adapt. Of course, plant breeders will do their best.

We are now collaborating with experienced plant breeders in Mozambique for a project funded by AusAid. However, it takes at least a decade to develop new cultivars and even longer if you are not sure what it is you are trying to change.

In the end, it is better to stop a problem before it happens and reduce the release of CO_2 into the atmosphere, and urgently.

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