serious threat to the continued efficacy of *Bt* toxins.

In the recent issue of *Science*, David Heckel and his colleagues[4] from the Department of Genetics, University of Melbourne, Australia, Clemson University and North Carolina University, USA, have identified a recessive gene that confers much of the resistance to *Bt* toxin in the tobacco budworm, *H. virescens*, a key pest of cotton and other crops. This is an important finding, considering the fact that this lepidopteran pest is the primary target of recently commercialized transgenic *Bt* cotton, which kills all budworm moths, except rare individuals that contain a pair of recessive genes for resistance, by providing the insecticidal Cry1Ac toxin from *Bt*. Although *Bt*-resistant populations of *H. virescens* have not yet been observed in the field, the previous studies by Gould and his colleagues[5,6] established that 1.5 of every 1000 moths carry one of the genes for resistance to the *Bt* toxin. Based on this frequency of resistance, the researchers predicted that it would be likely to take about 10 years of *Bt* resistance in budworm moths to become a problem, when *Bt* cotton is widely planted. The study reported in *Science* led to the identification of a single major gene (*BtR-4*) which is responsible for 40 to 80% of Cry1Ac resistance levels in the line YHD2, a resistant strain developed in the laboratory by selection with toxin-impregnated diet. The previous studies by Heckel and his colleagues[7] have assigned *BtR-r* to the linkage group 9 (LG 9).

In the study reported in *Science*, the authors have further localized the *BtR-4* on LG 9 by analysing 11 polymorphic markers that scanned a total genetic length of 105 centimorgans (cM) on a segregating backcross family of 48 progeny of a hybrid male and a YHD2 female. The scanning of LG 9 for resistance QTLs (quantitative trait loci) using interval mapping[8] indicated the likely location of *BtR-4* on LG 9. They have further shown that the *BtR-4* is a null allele of the cadherin superfamily gene. The functional copy of the cadherin gene is known to encode a cell adhesive protein which binds to Cry1Aa with high affinity and brings about cell lysis in *Bombyx mori* cells[9]. The authors elegantly show that the resistant allele of this gene is created by the insertional inactivation of the functional allele of the cadherin gene by a deleted copy of the retrotransposable element, *Hel-1*. The *H. virescens* larvae, which carry disrupted allele of the cadherin gene in homozygous condition develop resistance to the *Bt* toxin Cry1Ac, since *Bt* toxin in cadherin-deficient larvae is unable to bind to midgut cells of heliothine larvae to execute cell death.

The findings reported by Heckel and colleagues[4] provide an efficient tool to detect recessive resistant alleles in heterozygous condition. This finding is a major advancement since conventional bioassay-based monitoring methods, which score the number of moths resistant to *Bt* toxin, are not sensitive enough to detect resistant individuals that carry recessive alleles in homozygous condition, because of extreme rarity of resistant homozygotes in the populations. Since heterozygotes could be genotyped efficiently, the monitoring of frequency of resistant alleles in the population will indicate whether the problem is looming, well before resistant homozygotes become frequent enough to cause uncontrollable outbreaks, the study reports.

In India, where *Bt* cotton is still undergoing field trials, it is very important to ascertain the existence of resistant alleles in the heliothine pest population before and after the introduction of *Bt* cotton. Although the existence of additional genes that confer resistance cannot be ruled out, as shown by Aroian and colleagues in *Caenorhabditis elegans* in the same issue of *Science*[10], the study reported by Heckel and colleagues[7] provides what seems to be a major gene for *Bt* resistance, which could be used for monitoring *Bt* resistance in the pest populations. Preservation of DNA samples of representative pest populations prior to introduction of *Bt* cotton and the subsequent comparison of resistant allele frequencies in the populations after the introduction of *Bt* cotton, will certainly provide informed tools for the efficient use of *Bt* transgenics in pest control.

1. Schnepf, E. *et al.*, *Microbiol. Mol. Biol. Rev.*, 1998, **62**, 755–806.
2. Schuler, T. H., Poppy, G. M., Kerry, B. R. and Denholm, I., *Trends Biotechnol.*, 1998, **16**, 169–175.
3. James, C., *Int. Serv. Acquisit. Agric-Biotechnol. Appl. Briefs*, 1998, **8**, 1–43.
4. Gahan, L. J., Gould, F. and Heckel, D. G., *Science*, 2001, **293**, 857–860.
5. Gould, F., Anderson, A., Reynolds, A., Bumgarner, L. and Moar, W., *J. Econ. Entomol.*, 1995, **88**, 1545–1559.
6. Gould, F. *et al.*, *Proc. Natl. Acad. Sci. USA*, 1997, **94**, 3519–3523.
7. Heckel, D. G., Gahan, L. J., Gould, F. and Anderson, H., *J. Econ. Entomol.*, 1997, **90**, 75–86.
8. Lander, E. S. and Botstein, D., *Genetics*, 1989, **121**, 185–199.
9. Nagamatsu, Y., Koike, T., Sasaki, K., Yoshimoto, A. and Furukawa, Y., *FEBS Lett.*, 1999, **460**, 385–390.
10. Griffits, J. S., Whitacre, J. L., Stevens, D. E. and Aroian, R. V., *Science*, 2001, **293**, 860–864.

ACKNOWLEDGEMENTS. I thank Dr Seyed E. Hasnain for a critical reading of the manuscript.

J. Nagaraju is in the Laboratory of Molecular Genetics, Centre for DNA Fingerprinting and Diagnostics, ECIL Road, Nacharam, Hyderabad 500 076, India (e-mail: jnagaraju@www.cdfd.org.in).

Can insects seriously affect the power output of wind turbines?

P. N. Shankar

The purpose of a large, well-designed wind turbine (Figure 1) is to efficiently extract energy from the wind. This it does by having carefully designed and manufactured blades whose sections are smooth, streamlined aerofoils with nice rounded leading edges and sharp trailing edges (see Figure 2 *a*). As shown in Figure 2 *a* it is very important for the efficient performance of the windmill that the airflow be attached to the aerofoil section and that the streamlines are, as far as possible, smooth and steady. The twisted wind turbine blade is designed to try to achieve this.

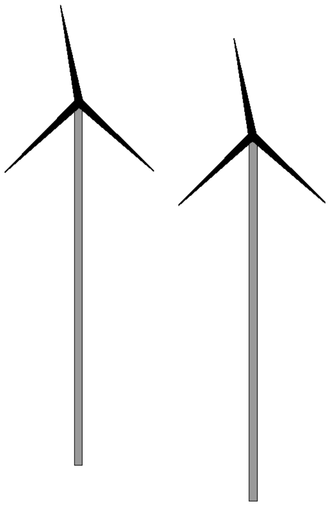

Figure 1. A sketch of horizontal axis wind turbines with three twisted, high performance blades each, the cross-sections of which are aerofoils.

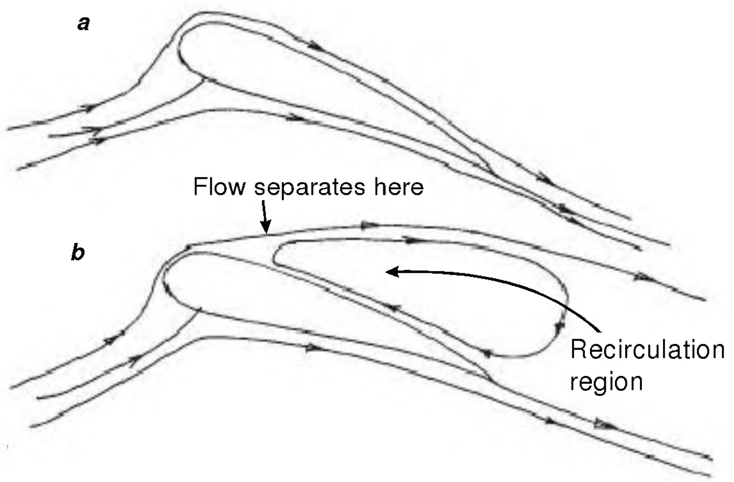

Figure 2. Airflow past an aerofoil. ***a***, Smooth, streamlined flow past an unstalled aerofoil. Note that the flow is everywhere attached to the aerofoil. ***b***, Separated flow past a stalled aerofoil. Note that the flow separates from the upper surface at some point. This can happen if there is roughness near the leading edge.

There are a number of factors that can adversely affect the performance of a wind turbine. Low and high wind speeds, gustiness and poorly maintained equipment can all lead to performance degradation. But there are others too. Unpredictable changes in power levels have been noted in wind farms with the power sometimes falling to even a half of the expected power. Thus, for the same nominal wind speed the output may have two or even more values.

As pointed out earlier, the turbine performance is critically dependent on the flow over the blade section being streamlined and *attached* as in Figure 2 *a*. However, there are circumstances when the flow separates from the section as in Figure 2 *b*. In this case the primary flow *separates* from the section at some point called the *separation point* and beyond that point the airflow, near the aerofoil, actually proceeds in a direction in opposition to the primary flow. The latter flow is called *reversed flow* or separated flow. In any case, generally, such flow separation is detrimental to the performance of the aerofoil and is to be avoided. Flow separation can take place because the angle of attack is too high or because of the presence of roughness near the leading edge, for example.

Recently, Corten and Veldkamp (*Nature*, 2001, **412**, 41–42) have come up with convincing evidence that suggests that dead insects contaminating the leading edges of the blades can seriously affect high speed wind turbine performance. Insects, which prefer to fly in conditions of low wind speed and high humidity, increasingly foul the leading edges of the blades. At low wind speeds, when the blade angle of incidence is small, the flow remains attached in spite of the fouling of the leading edge and there is little degradation in performance. But at high wind speeds, when the so-called suction peak is high, the flow separates because of the fouled leading edge, and the performance is seriously affected.

Corten and Veldkamp obtained solid experimental evidence to support their hypothesis. They obtained this with the use of a novel flow separation detector fitted onto normal turbine blades and to ones whose leading edges had been artificially roughened to simulate impacted dead insects. They showed (Figure 3) that leading edge roughness did indeed degrade high speed performance.

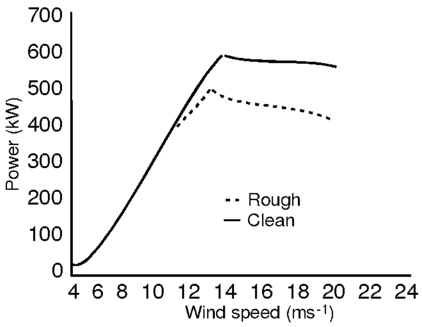

Figure 3. Schematic of the power output from wind turbines having clean blades and ones having blades with roughness. Note that the low speed performances are almost identical; roughness degrades the high speed performance.

The message is that high performance turbine blades have to be kept clean if they are to perform at peak efficiency. But there is, in these difficult times, a broader message. We ought to examine all the equipment that we use and make sure that they are maintained at peak condition. The kettle whose element has a thick carbonate coating, the pump whose bearings are shot, leaking water faucets, automotive engines spewing out smoke, etc. are all worthy of our serious attention and are reminders that we need to change to a more maintenance-conscious way of life. It is easier and ecologically sound to prevent waste rather than to generate new resources alone.

P. N. Shankar is in the CTFD Division, National Aerospace Laboratories, Bangalore 560 017, India (e-mail: pns@ctfd.cmmacs.ernet.in).