

## Field Kit to Characterize Physical, Chemical and Spatial Aspects of Potential Primate Foods

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### Key Words

Feeding · Food chemistry · Food physics · Mechanics · Colour vision · Diet · Spatial ecology · Geographic Information Systems

### Abstract

An outline is given for a field kit aiming to substantially increase the in situ knowledge gleaned from feeding studies of primates. Measurements are made of colouration (spectrum of non-specular reflection) and many mechanical, chemical and spatial properties of primate foods.

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### Introduction

Optimal foraging by primates may have as much to do with the spatial distribution of feeding trees and their relative crop sizes as with the physicochemical character of their foods [1–6]. Despite long-standing interest in how the latter properties influence primate feeding, it is difficult to make accurate measurements in the field. Food properties such as size, weight, colour and mechanical characteristics must be measured almost immediately while the specimen is fresh since these features are obviously susceptible to rapid and various changes during drying and storage. Analysis of chemical properties is also recommended on a fresh basis [7]. However, due to a lack of appropriate methodology, the chemical constitution of plant parts has typically been con-

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ducted on dried specimens in a laboratory environment. Thus, the long delay between collection and measurement has arguably impeded progress: any scientific study benefits from data collection tailored towards the most profitable lines of inquiry. A long time lag before analysis may produce the need for extra field seasons. Evaluating results from pilot studies is critical to many research proposals and successful fieldwork. If those results are obtained slowly, then knowledge will advance likewise. In this regard, classic methods of fine-scale vegetation mapping are often laborious and not outstandingly accurate [8].

Here we describe a field kit for comprehensive physicochemical characterization of primate foods. The aim is to characterize food attributes discernible by the primate sensory system, which could influence feeding behaviour, rather than a nutritional analysis. Results are obtained quickly and with accuracy comparable to that of a standard laboratory. The kit has been used at Makerere University Biological Field Station, Kibale Forest (Uganda), Beza-Mahafaly Special Reserve (Madagascar), and Marengo and Murcielago (Costa Rica).

### **Methods, Objectives and Requirements**

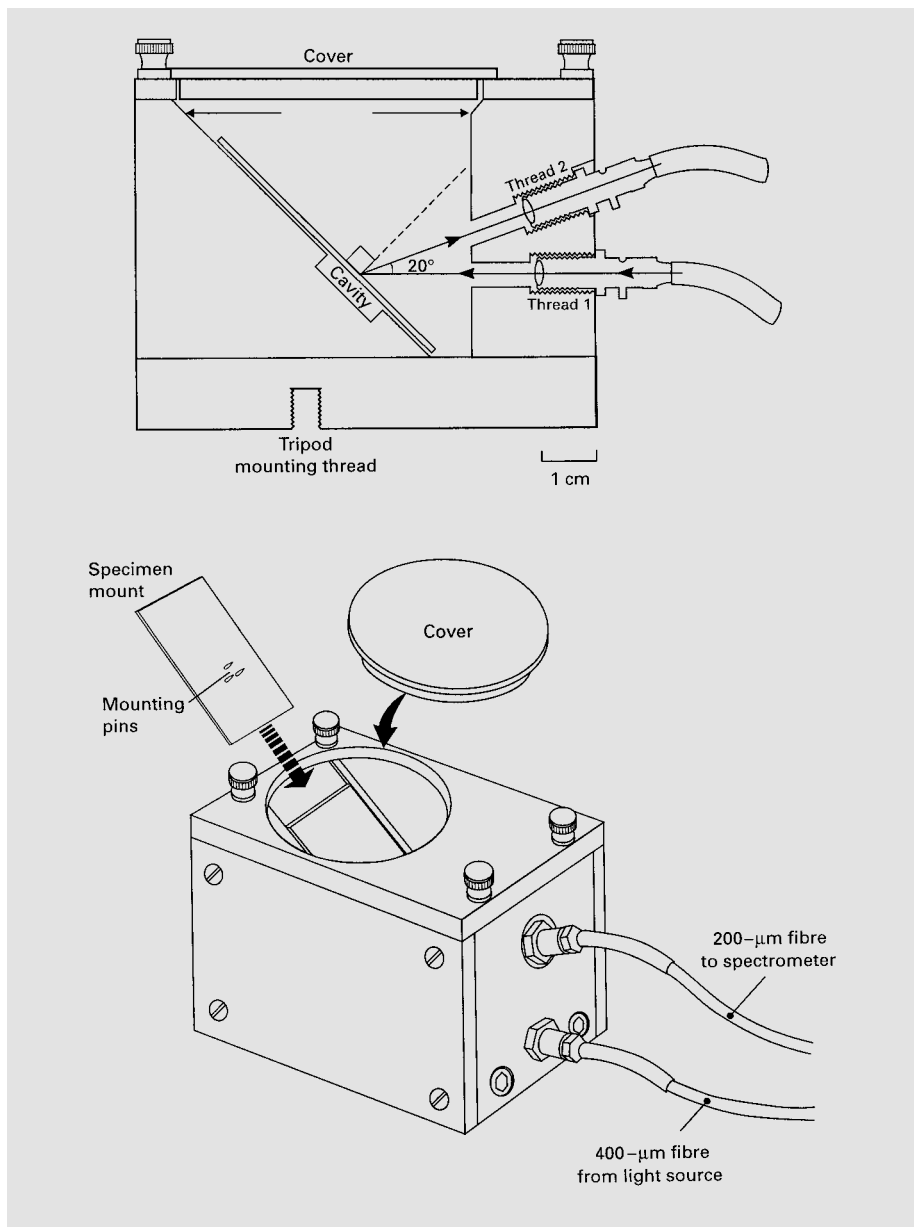
The kit has four main components: (i) a mechanical tester purpose-built for work on primate foods, whether of plant or animal origin, (ii) a low-cost spectrometer for measuring colour (e.g. of foods or chemical reaction products), (iii) a PC with a data acquisition card that runs integrated software and (iv) equipment for Global Positioning System (GPS) monitoring and Geographic Information Systems (GIS) software. Most measurements are made with some combination of the above, although an additional number of ancillary chemical tests do not require the spectrometer. While sources of electricity and clean water are essential, a small array of solar panels and mineral or filtered water may suffice to meet these needs.

### **Food Physics**

Physical properties of plant foods include colour, geometrical and mechanical characteristics. These features may form important sensory cues for food detection, selection and subsequent processing by primates.

#### *Colour*

The appearance of a potential food is likely to serve as an important physical feature cueing long-range foraging by primates. The colour of a potential food item is one of its most salient features. This depends foremost on its reflection spectrum, which is measured relative to a known standard (in this field kit, a fresh surface of barium sulphate powder). We use a small spectrometer (S2000 fitted with diffraction grating No. 2 which admits light from 200 to 850 nm, Ocean Optics, Dunedin, Fla., USA), measuring approximately  $14 \times 11 \times 4$  cm, connected to a data acquisition PC card and powered by the PC itself. Illumination is by a 12-volt 3,100-kelvin tungsten halogen lamp (LS-1, Ocean Optics), which gives adequate visible light between 350 and 700 nm. Small (approx.  $3 \text{ mm} \times 3 \text{ mm}$ ) samples are placed in a purpose-built chamber (fig. 1). Light from the LS-1 is focused onto the specimen via a  $400\text{-}\mu\text{m}$  diameter patch fibre-



**Fig. 1.** Side and top views of the optical specimen chamber for recording either food colour or ambient illumination. To record either, a brass pot containing packed barium sulphate powder is placed in the cavity with the specimen mount removed. Light from the LS-1 lamp passes through an optical fibre and is focussed via a lens housed in thread 1 onto the surface of the powder. The reflection passes back through the lens mounted in thread 2 in an optical fibre to the spectrometer. To record food colour, specimens are placed on the specimen mount and the aperture is closed by the cover. To record ambient illumination, the aperture is opened to allow sunlight to enter, while the LS-1 is disconnected. For this purpose, the chamber can be mounted on a tripod via the thread in the base of the chamber.

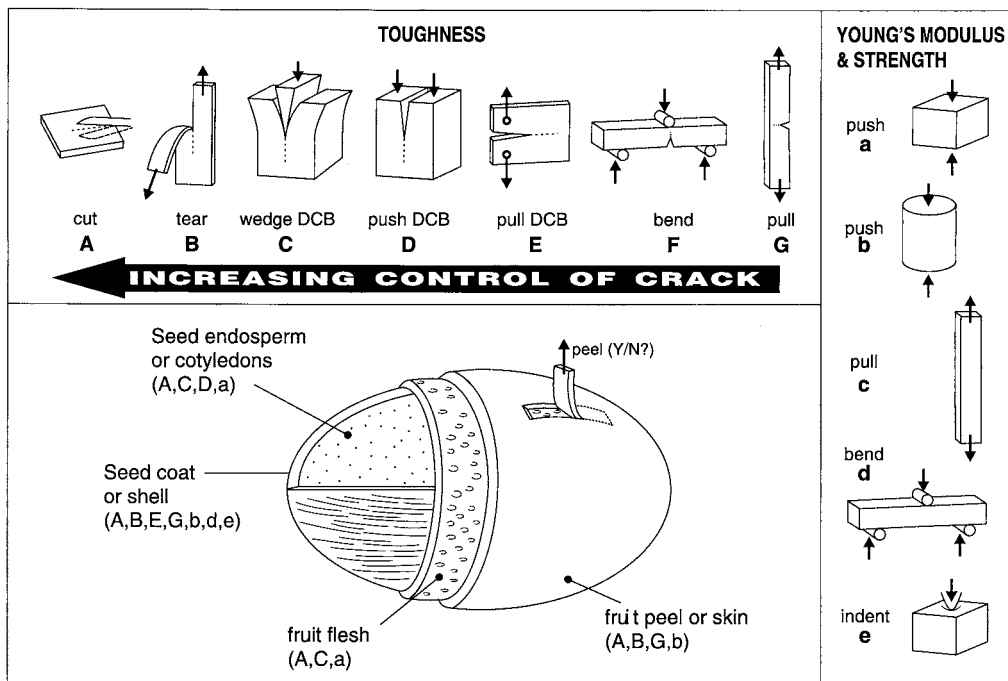
optic cable and lens (Ocean Optics). Reflected light is collected by a second lens and conducted via a 200- $\mu\text{m}$  fibre cable (Ocean Optics) to the spectrometer's diffraction grating. A significant problem in measuring the dark, shiny surfaces sometimes found on leaves and fruits is that reflected light has two sources: diffuse light scattered back from the material, which is normally taken to be the object colour, and a specular reflection from the surface, which gives rise to a variable glossiness. In order to record colour, it is important to separate the contribution of the specular component from its diffuse reflection. This is achieved through (a) placement of the specimen surface at  $45^\circ$  to the incident illumination, and (b) 20-degree axes between the illumination and recording lenses (fig. 1). This arrangement produces a negligible specular (spectrally flat) component in measurements from flat surfaces. The basic spectra recorded, however, do not indicate the colour that a primate perceives. In order to model primate perception effectively, spectra require analysis accounting for the chromatic coding sensitivities of the different retinal photopigments found in primates [9–11]. Effective modelling requires additional information on the background colour against which a potential food is viewed as well as the characteristics of illumination. All the equipment mentioned above, minus the lamp, may be taken outdoors into the field in order to record characteristics of solar illumination as variably affected by cloud cover and vegetation [12]. This is somewhat cumbersome and obviously not possible while routinely observing animals. The light intensities in which animals are feeding are recorded with a photographic light meter (Flashmate L-308BII, Sekonic, Tokyo, Japan – set to an 'EV' setting at ASA 8000).

#### *Geometry*

In addition to standard measurements like weight (AND SV-120 battery-powered portable balance reading weights up to 120 g accurately to 0.01 g, Cole-Palmer, USA) and basic dimensions (using calipers and a thickness gauge), all plant items are video-recorded using a mini digital video camera (GR-DVXE, JVC, Tokyo, Japan). For this purpose, the camera was mounted on a tripod approximately 60 cm above a specimen lying on a matte grey background. The sound track on the video camera provided a simple, convenient medium for recording field notes. Information regarding the plant item, the various parts eaten or rejected and the manner of ingestion by the primate were juxtaposed with the image of the item. In addition to providing a medium for quantification of ingestion rates, the video record provides images of plant items that are easily downloaded onto a computer for later analysis of shape.

#### *Mechanics*

The acquisition and processing of foods by primates involves deformation, fracture and fragmentation. All these events are heavily influenced, if not controlled, by Young's modulus and the toughness of foods [13]. These fundamental properties can be measured by a set of tests (fig. 2), using a special-purpose mechanical tester [14]. The mechanical stage of the tester houses either a 10-newton or a 100-newton load cell and features an array of test jigs to perform these tests. Two types of tests are performed. Young's modulus of a material is the stress-strain ratio at small deformations and is a measure of the resistance to elastic deformation [15, 16]. All tests of Young's modulus shown in figure 2 can be performed as appropriate. Toughness is an energetic property and thus ideally suited for understanding feeding behaviour in an ecological context [17]. It is defined as the work done in propagating a crack through a material normalized



**Fig. 2.** Types of tests made with a field mechanical tester [14]. Tests of Young's modulus are relatively standard and have an accuracy that depends largely on accurately shaped specimens. Bending and compression tests are easier to run in the field than tensile tests. Toughness tests require control of a crack that propagates through a specimen. Crack control depends on test geometry and on the material being tested.

to the crack area that is produced [18, 19]. Tests must be designed so as to include only that energy associated with crack growth. All toughness tests shown in figure 2 can be made with the field kit, but the most common ones that we have used are A–C. The procedures for most tests [15] are based on a rationale derived from texts in materials science [18] and fracture mechanics [19].

### Food Chemistry

With few exceptions [20, 21], field biologists have nearly always analysed plant chemicals from dried specimens. Although these methods are simple and often necessary due to the limitations of fieldwork, drying is a less than ideal preservation technique since unknown and uncontrolled post-mortem changes may introduce uncertainty into later analyses. Moreover, further complications may arise from the introduction of new compounds created during pathological reactions [22]. Although Gartlan et al. [23] found a correlation in phenolic levels between fresh and dried leaves of several species, there was an overall and inconsistent loss of extractable phenols during drying. Studies also report a significant loss of tannins during traditional drying techniques

[24], with losses of condensed tannin as high as 20 mg g<sup>-1</sup> in air-dried leaves [25]. Thus, the unknown effects of drying on other plant compounds and the overall uncertainty of drying techniques make the chemical analysis of fresh plant material ideal. With recent technical innovations, we can now study food chemistry in the field, at last making it possible to analyse the foods as eaten by primates. We have based our tests on spectrophotometry because of the availability of a portable spectrometer eminently suited to field conditions. A 1-cm UV cuvette holder (Ocean Optics) is used in line with a neutral density filter (optical density 3.0, Omega Optical Inc., Brattleboro, Va., USA) to prevent saturation of the detectors in the spectrometer. The spectrometer is also used for assessing the colour of a plant item by spectroradiometry (see above). We decided against chemical methods that involved complex extractions, centrifuging or chromatography due to the quantity of equipment needed (though some field sites, such as Kibale, have permanent facilities for this in purpose-built laboratories). This decision limits the food chemistry that can be explored (e.g. it excludes detailed analysis of sugars or lipids), but we nevertheless believe that this field kit represents a significant advance on current practices.

#### *Basic Requirements*

The fundamental requirement is water quality. Rainwater is used at Kibale. Rain run-off from a corrugated iron roof is collected in an iron drum and then boiled. It is then passed through a ceramic (Hindustan, India) and membrane filter (Krimskaya Rosinka, Ukraine) before passage through a low-cost deionizer (D0800, Barnstead Thermolyne, Dubuque, Iowa, USA). Whether all this is strictly necessary is debatable. At Beza-Mahafaly, bottled mineral water is being used successfully. It is worth noting, however, that the chemical composition of a brand of bottled water may not be standardized and/or may be different from that described on its label. Nevertheless, chemical 'blanks' (all constituents of the test except for the homogenized plant tissue) at Beza-Mahafaly are only marginally higher than are those at Kibale. Since each test is performed as a micro-assay in 1.5-ml Eppendorf microtubes, accurate measurement of small quantities is critical. Adjustable pipettes are needed (we use 20- $\mu$ l, 200- $\mu$ l and 1-ml pipettes – Pipetman, Gilson, Villiers-le-Bel, France) with a balance accurate to 0.01 g at least. For cuvettes, there is a choice of quartz, glass or disposable plastic materials. We prefer the optical clarity of quartz. Plastic cuvettes are not recommended since they stain quickly and are difficult to clean properly. Furthermore, plastic is attacked by the acetone used in the ninhydrin test for free amino acids.

#### *Chemical Extracts*

Extraction techniques for quantifying phenolic compounds, including a review of the various solvents possible, have been discussed by Waterman and Mole [22]. We decided to use 50% methanol as a solvent. Approximately 0.1 g of plant tissue is weighed, cut into approximately 1-mm pieces and placed in a 20-ml specimen tube. Five millilitres of 50% methanol are then added and cells are homogenized within 2 min with a tissue homogenizer (Tissue Tearor, Dremel, Racine, Wisc., USA). These homogenizers operate from a main electrical source or rechargeable batteries (which may be charged by an inverter connected to a solar supply). A mortar and pestle can be substituted for a homogenizer, though this is slower and less controlled. The homogenate is then collected into a 5-ml plastic syringe fitted with a Luer lock. This is attached to a plastic filter holder containing a glass fibre filter (1.6  $\mu$ m pore size, type 1, Millipore,

USA). Slowly depressing the plunger of the syringe forces the homogenate through the filter and into a 1.5-ml Eppendorf microtube for storage at 4°C. Provided that homogenization is thorough, the filter will not clog.

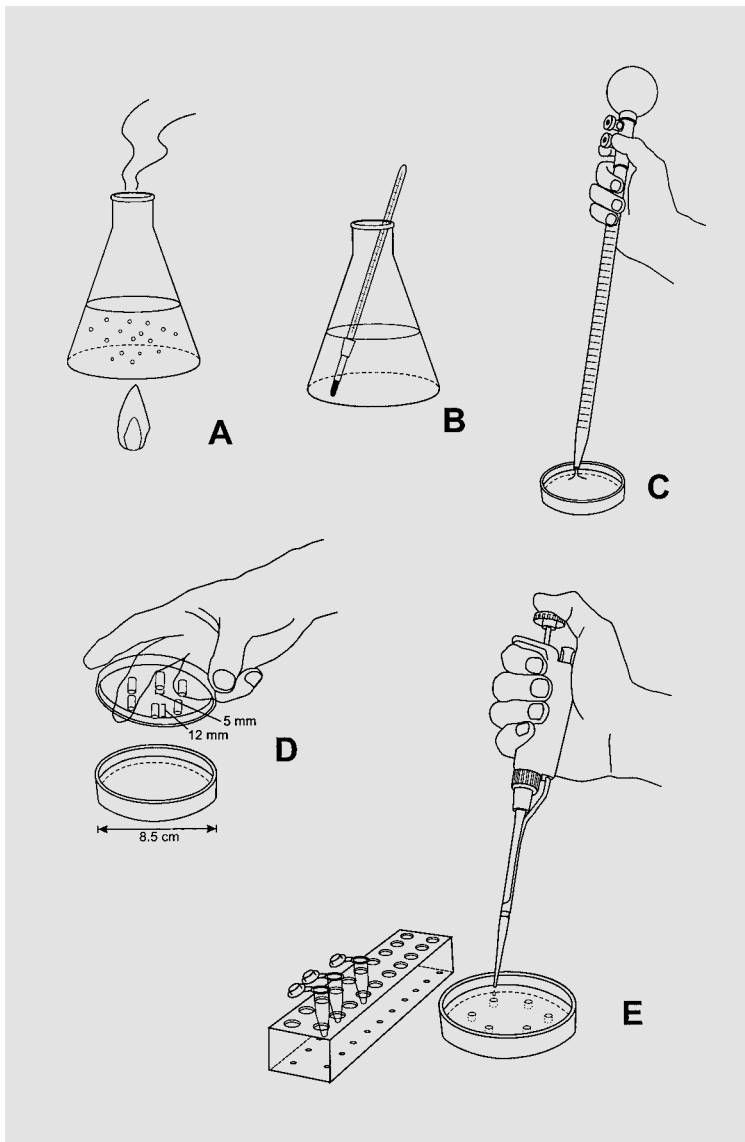
#### *Actual Tests*

Our tests are recorded on a fresh-weight basis rather than the traditional dry-weight basis that is generally reported. The simple rationale is that the concentration of a chemical in a food, which is what sensory perception must depend on, must take into account the moisture content of the food.

*Phenolic Compounds and Tannins.* Levels of phenolic compounds are measured by the Prussian blue test [26–28]. In order to better suit field conditions and reduce waste, we perform the test as a micro-assay, reduced to a 1.5-ml Eppendorf tube [i.e. 300 µl dH<sub>2</sub>O + 10 µl sample + 100 µl 0.0016 M K<sub>3</sub>Fe(CN)<sub>6</sub> + 100 µl 0.02 M FeCl<sub>3</sub> in 0.1 M HCl + 1 ml stabilizer]. Results are expressed as equivalents to 6-point standard curves based on the following references: gallic acid (Aldrich, Milwaukee, Wisc., USA), sorghum husks (DC-75 international hybrid at 16% moisture content, of which the husks are condensed tannins – supplied by Dr. T. Beta) and tannic acid (Riedel-de-Haën, Seelze, Germany). Although inexact in composition, tannic acid represents a mixture of phenolic compounds and water-soluble tannins. For more precise measures of tannin, we insert sample extracts into 5-mm diameter wells made in bovine-serum-albumin (BSA)-containing agarose gels [29]. Although the original protocol for the radial diffusion assay requires a 5-mm diameter well punch to create wells for the plant extracts, we prefer to outfit the lid of a Petri dish with 5-mm diameter acrylic pins (fig. 3). These lids are placed over the hot agarose solution and removed after the gel has solidified. Details of the test as conducted in the field are shown in figure 3. Tannin measures are expressed as equivalents to 6-point standard curves based on tannic acid, sorghum husks and crude quebracho tannin (gift of Dr. A.E. Hagerman, University of Miami, Oxford, Ohio, USA). More information may be obtained by differentially staining the gel to yield rings for water-soluble and condensed tannins [30], but these methods appear too complex for the field.

*Amino Acids.* Levels of non-protein ‘free’ amino acids are based on the ninhydrin reagent (Sigma, St. Louis, Mo., USA) diluted to a 0.1% solution in acetone. When 1 ml of reagent is added to 100 µl of sample and heated in a water bath to 90°C, three colours may be produced depending on the amino acids present. In order to construct a field test, we looked at absorption peaks of 10 pure amino acids (Sigma) produced with this reagent. The most common peaks were approximately at 350, 415 and 575 nm [31]. Examples of amino acids that have peak absorbances at these wavelengths are asparagine, aspartic acid and glutamic acid, respectively. Since these are relatively common in plant tissues, being involved in xylem and phloem transport [32], these three compounds were chosen to construct 6-point standard curves at these respective peaks, with results expressed as percent equivalents. Actual values obtained from tests will vary with conditions such as the rate or time of heating and the exact temperature of the water bath [31], which are difficult to control precisely in the field. We are, therefore, using this test as a rough indicator of the presence of free amino acids with the possibility of identifying amino acids in amino-acid-rich extracts after fieldwork.

*Protein.* We use the Coomassie blue (Coomassie brilliant blue G-250, Sigma) test [33], amended by Read and Northcote [34] to ensure a similar response with very diverse proteins. This allows the quantity of protein per se to be estimated rather than



**Fig. 3.** Radial diffusion assay [29, 30] adapted for assessing tannins in the field. **A** 1 g agarose (type I: low electroendosmosis, Sigma)/100 ml buffer is boiled. **B** Then it is allowed to cool to 40–45 °C before adding 0.01 g BSA (Fraction V, Sigma)/100 ml buffer. **C** With a plastic burette, 25 ml of solution is transferred to a plastic Petri dish. **D** The lid of this dish has flat-ended acrylic pins, 5 mm in diameter and 12 mm in length, which produce accurate wells without the need for a well punch. **E** 40- $\mu$ l aliquots of plant extract are dispensed into each well and left for 96 h. The size of any rings that have formed may be measured with dial calipers. The results are referred to standard curves based on tannic acid, sorghum husks and quebracho.

the amount of nitrogen from the more familiar Kjeldahl test. We follow Read and Northcote's recommendations in producing their dye reagent No. 1, with the minor difference of adding 50 µl of extract to 1 ml of Coomassie reagent (instead of 950 µl of reagent). Results are given as percent equivalents of BSA (Sigma). Though this protein is of animal origin, it is employed because it gives the widest range response of standard proteins that have been tested [34].

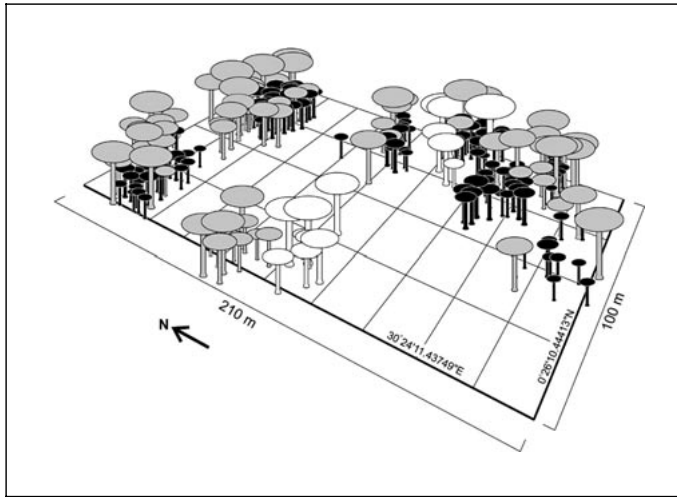
*Other Measures.* We use a solid-state pH meter (model 1001, Sentron BV, Roden, the Netherlands), averting the need for continual immersion of a standard electrode. It can measure the pH of all but the very driest foods. It is, for example, possible to estimate the pH of a mature leaf, though usually only from a major vein or the midrib. The meter is also used for adjusting the pH of the buffer used in the radial diffusion assay [29]. Soluble solids are assessed with a digital refractometer (Palette PR-101, Atago, Tokyo, Japan) that reads between 0 and 45% BRIX units. Use of this to measure approximate levels of sugars in flower nectar is long-standing [35], while it can also be used, though less effectively, to estimate sugar levels in fruits [36]. We are dubious about its value.

### **Spatial Ecology**

How organisms occupy and utilize space is implicit to any ecological investigation [37]. In this regard, the spatial distribution of plant foods within an animal's environment is an important physical feature influencing primate food selection [1, 38, 39]. For example, Glander [40] found that the distribution of secondary chemical compounds among proximal conspecific trees influenced howling monkey food selection. Due to this variability, ecological studies of food selection must account for the fine-scale relationships between the physicochemical properties of plant foods and their distribution in space. Quantifying these relationships may produce insights into an animal's perception of food in its environment and how it optimizes navigation and food acquisition. GPS technology integrated with GIS offers a potential means for accurately locating and quantifying ecological features on the surface of the earth [41, 42]. For this reason we include GPS and GIS technology in our field kit since it provides highly accurate and rapid quantification of the heterogeneity of primate food sources on multiple scales and dimensions.

It should be noted that prior to May 1, 2000, the greatest source of GPS pseudo-range error was selective availability, which referred to ephemeris errors (epsilon) and satellite clock errors (dithering) deliberately induced by the US Department of Defense. Presently, owing to the 1996 Presidential Decision Directive suspending selective availability on May 1, 2000, the magnitude of pseudo-range error (primarily from ionospheric and tropospheric delay) is improved to 10–30 m [43]. Unfortunately, while this degree of error is probably acceptable in most ecological applications, it is unsatisfactory for fine-scale vegetation mapping [44].

Since hand-held GPS receivers are incapable of sub-metre accuracy, this field kit uses a 12-channel GPS Pathfinder Pro XRS System (Trimble Navigation Ltd., Sunnyvale, Calif., USA) in combination with a subscription to a satellite differential correction service (Fugro-OmniSTAR, Houston, Tex., USA). The selection of this unit was based on the demands of a rainforest environment and the need for sub-metre accuracy. In addition to being battery powered and lightweight (1.35 kg) several properties of this



**Fig. 4.** Precise geographic co-ordinates of three clumped, primarily mammal-dispersed tree species near Kanyanchu (Kibale Forest). Black = *Uvariopsis congensis* (Annonaceae); grey = *Chrysophyllum gorungosanum* (Sapotaceae); white = *Balanites wilsoniana* (Balanitaceae).

backpack GPS are suited to meet rainforest conditions: (i) the capacity to simultaneously track 12 satellites, (ii) differential correction of spatial data in real time and (iii) rugged, waterproof housing. Provided specific all-or-nothing operating parameters are maintained, satellite-subscribed differential correction results in a small degree of error (within 50 cm root mean squared) [44, 45]. Data capture is expressed as latitudes and longitudes relative to a mathematical model called the World Geodetic System 1984 datum (or WGS-84). Co-ordinates in the WGS-84 model are based on an origin point and the GRS-80 ellipsoid, which most closely approximates the shape of the earth.

GIS applications transform ellipsoid co-ordinates into local rectangular, flat-earth models. These models allow rapid spatial analysis of the feature under study. For example, in our study we exported geographic data and feature attributes of three tree species from Trimble's Pathfinder Office software directly into ArcView GIS v3.1 (Environmental Systems Research Institute Inc., Redlands, Calif., USA). One possible feature of GIS (fig. 4) illustrates the three-dimensional configuration of primarily mammal-dispersed tree species. Since larger animals typically disperse larger seeds in clumps, patterns of seed deposition may influence the spatial dispersion of rainforest trees [46]. *Balanites wilsoniana* (Balanitaceae), for example, is a species believed to be solely dependent on elephant dispersal [47] and shows greater aggregation than either *Chrysophyllum gorungosanum* (Sapotaceae) or *Uvariopsis congensis* (Annonaceae). *C. gorungosanum* is commonly dispersed by both elephants [48, 49] and chimpanzees [50], and exhibits a more clumped dispersion than *U. congensis*, which appears to be heavily dependent on chimpanzees and cercopithecines for dispersal [50–52]. Although this example is on a small regional scale, quantifying the clumped distribution of trees in space may yield insights into the ecology of seed dispersal and patterns of forest compo-

sition. We believe these tools constitute some of the most advanced technologies used to date to quantify and plot the spatial features in a primate's environment.

In Kibale Forest, we have experienced one of the main limitations of GPS technology. A dense forest canopy poses a significant physical barrier to the strict all-or-nothing operating parameters necessary for differential correction [44]. Since dense canopy cover characterizes many environments where primates are found, we recommend using a telescoping antenna pole to send the integrated beacon/satellite antenna above the canopy or, when necessary, climbing a tree with the unit in order to escape as much interference as possible.

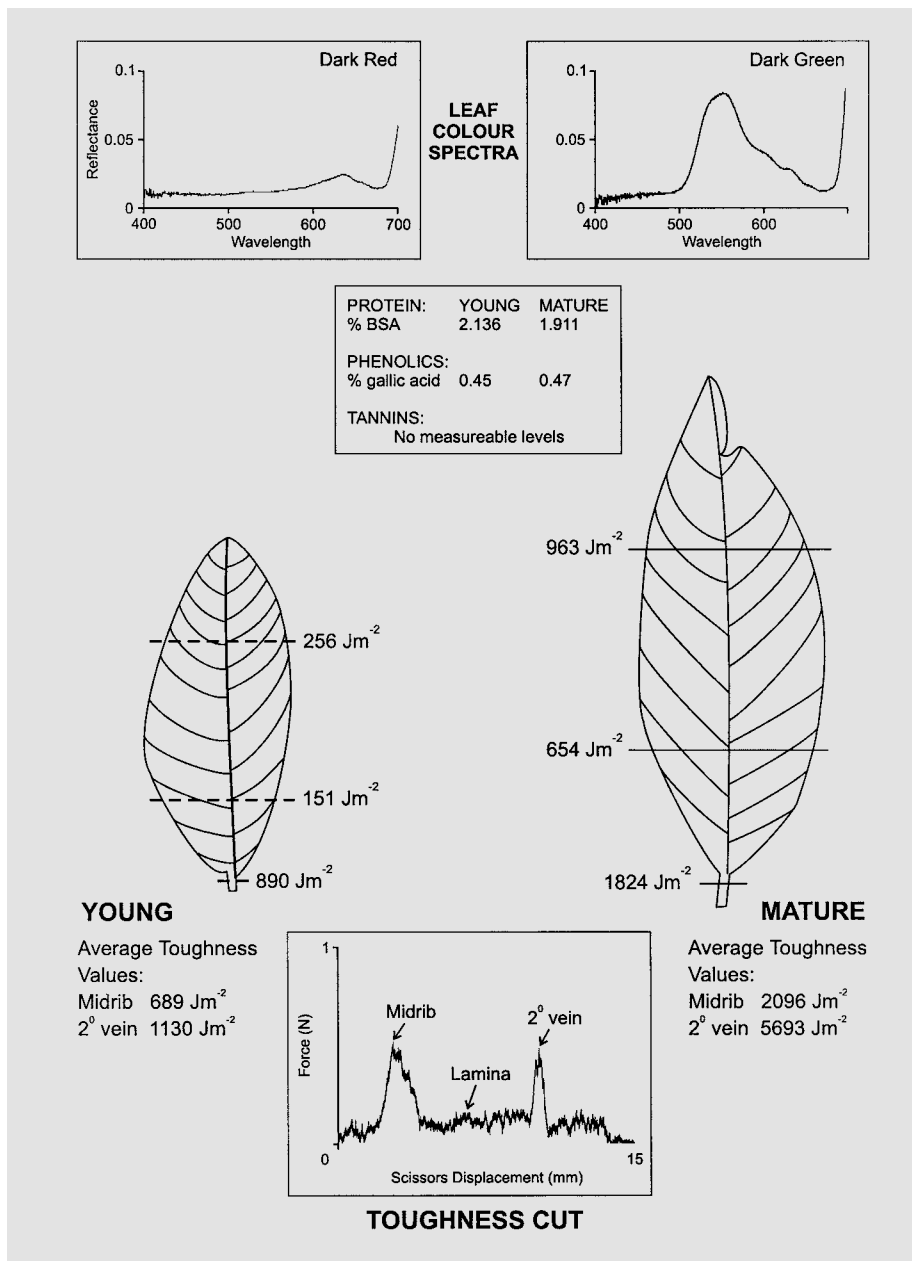
### **Data Collection**

It is now becoming routine to take notebook computers to the field as these become more reliable, lighter and consume less power. Nearly all the data generated from using this field kit are collected digitally in real time using a single software environment (LabView, version 5.0.1, National Instruments, Austin, Tex., USA). Data acquisition is via a low-cost 12-bit A-to-D PC card (DAQCard1200, National Instruments) connected to a junction box that switches between data acquisition from the mechanical tester and spectrometer. All acquisition programs are written in LabView, a programming language based on data flow rather than line-by-line interpretation. The spectrometry programs are adapted from a commercial program (Driver software for spectrometers, World Precision Instruments Inc., Sarasota, Fla., USA). Most of the analysis can be conducted in a LabView environment and some files are shared between programs, all of which can reside in computer memory simultaneously. These programs are available on our website (<http://web.hku.hk/~ppproj>).

### **Evaluation**

In 5 years of producing the mechanical testers, the calibration of the load cells and the associated electronics have proved very stable over long periods. Scissors cutting tests are run most frequently: these tests have been run in the laboratory on universal testing machines and with various types of scissors. The sharpness of scissors is responsible for most of the variation in results, but this factor is not great unless the material being tested exhibits elastic crack-blunting (which is not typical of plant tissues) or else the scissors are allowed to become very blunt [14]. Load cells have broken through overloading, particularly the 10-newton cells. Load limitations remain a big drawback to field mechanics that can only be circumvented by making very small specimens. High modulus foods, such as the woody coverings of seeds can be difficult to test because of high loads. The accuracy of the spectrophotometry set-up was tested by taking a plant extract containing phenolic compounds and running 20 tests in the field spectrometer and a commercial UV-visible laboratory spectrometer (Helios 3000 UV-Vis Spectrometer, Unicam, Cambridge, UK). The coefficient of variation of the field spectrometry set-up was 0.53% compared to 0.01% in the laboratory device.

The software has proved easy to use and provides rapid results. All programs, for colour, mechanics and chemistry, can be held in memory at once. Figure 5 shows sample results obtained in Kibale for *Markhamia platycalyx* (Bignoniaceae) leaves. The



**Fig. 5.** The physicochemical properties of two age stages of *Markhamia platycalyx* (Bignoniaceae) leaflets frequently eaten by *Ptilocolobus badius* and *Colobus guereza* at Kibale. The laminae are eaten when dark red but not when dark green. Dark red leaves are less tough and contain more protein than dark green leaves. Using the force displacement curves generated by the mechanical tester, the midrib and prominent veins can be isolated on a plot. By assuming a circular cross-sectional area, the toughness of these structures can be obtained without dissecting them from the intervening lamina (which gives a relatively constant and much less tough 'background').

young age stages are eaten extensively by red colobus (*Piliocolobus badius*) and black-and-white colobus monkeys (*Colobus guereza*) while the laminae of mature leaves are not. It can be seen that the ratio of protein:toughness is very much higher in the young leaves than mature ones.

## Discussion

The accuracy of data obtained from the field kit depends on several sources of error, e.g. drift from calibrated values, wear, dust, corrosion and the skill of the user. However, there is every reason to suppose that laboratory equipment could be used with reasonable accuracy for fieldwork in the tropics, particularly when at a field station where conditions parallel those in laboratories in many tropical universities (and where work on a par with that in temperate countries is possible). A power source (which can be solved by solar energy where sufficient sunlight is available) and some degree of protection from the elements are essential, but our equipment appears to meet these requirements. The methodology described above appears to break new ground. Equipment for portable spectrometry and mechanical testing (modelled on sound principles employed in universal testing machines) has not been available to fieldworkers. The principles of spectrometry and mechanics have to be learned in order to use the equipment, but a comprehensive manual has been written (to be available from our website) which explains some of the concepts behind the procedures and gives key references. For chemistry, there is no limitation on further work in a laboratory back home. In the field, good chemistry depends on good water.

Though primatology has come a long way from the pioneering methods of food processing [20], there are obvious flaws and gaps in the field kit that we describe here. It was designed to concentrate on features of the diet that can be sensed and thus which relate most clearly to feeding decisions that a primate may make. Accordingly, toughness is measured, but not fibre. The biggest flaw in the chemistry is common to most post-processing studies – that a reliance on chemical equivalents without knowledge of what is actually present in the plant tissue eaten is not a very satisfactory basis for firm judgement. Some tests are of limited accuracy, such as the ninhydrin test. However, amino acid analysers are becoming fairly commonplace and a suitably cleaned extract should be capable of analysis in this way. Further analyses would be necessary to establish if these are nutritive (e.g. aspartate and glutamate accumulate in the mesophyll of leaf blades and could clearly be important nutrients) or toxic [53, 54]. Some categories of compounds, such as terpenoids or alkaloids, are not assessed at all; this is difficult, however, even in full-scale laboratories. Fibre is not evaluated in the field kit. This reflects our view that this only affects feeding via its toughness [17, 55]. Last, but not least, it should be noted that the usefulness of the entire field kit is completely dependent on good and detailed observations of foods eaten.

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