An inexpensive field instrument for deep UV kava testing: Practical considerations.

http://kavascience.org

The recent article by Lebot and colleages demonstrates a simple method to test if a kava is noble, tudei or wiichmannii by measuring the ratio of absorbance of diethyl ether kava extract using 2 specific wavelengths of ultraviolet light: 250 nm and 290 nm:

"Colorimetric assessment of kava (Piper methysticum Forst.) quality", Tiphaine Lhuissier, Pierre-Edouard Mercier, Serge Michalet, Vincent Lebot and, Laurent Legendre, *Journal of Food Composition and Analysis 59 (2017) 27–34*.

So, I am thinking: how can one build an inexpensive instrument based on this test that could be used in the field?

We need a few things:

1. A source of light of those specific wavelengths.
2. A way to separate the wavelengths of light
3. A light detector.
4. An enclosure to hold the sample, and block external light from the detector.
5. Electronics to control the instrument and give a read out from the detector,
6. We also need to consider the availability of the chemicals used for the test.
7. Safety considerations

The wavelengths 250 and 290 nm are in the deep UV, or UV-C (and the far end of UV-B): https://en.wikipedia.org/wiki/Ultraviolet#Subtypes

This is very energetic light. It is used to kill bacteria in water and air. Generally, light with such a short wavelength is blocked from reaching the surface of the Earth by the ozone layer. Effects of direct exposure to the light could include: sunburn, damage to the eyes, or skin cancer. Therefore it is essential that the instrument be designed in such a way that the light source is never exposed when it is turned on.

There are not many good low cost options for generating light of both of those wavelengths. However in the case of 250 nm light, cheap low pressure mercury vapor lamps are available. These lamps emit a very pure and narrow line of light at 253.7 nm. In fact, conventional fluorescent lighting consists of a low pressure mercury vapor lamp enclosed in glass which does not transmit UV light that is coated with phosphors that convert the UV light into visible light. But the lamps are also sold enclosed in quartz, which allows the UV to pass through, for disinfection applications. For example:

Pulsrite 5003 Germicidal Tube Lamp: USD $6.77 each, Lifetime: 3,000 hours. https://www.1000bulbs.com/product/5185/AU-LGTL3.html

These lamps do have another line at 184.9 nm, but it is blocked if the casing is made of natural quartz. (If the 185 nm line were not blocked, it would be absorbed by the oxygen in the air, generating ozone in the process.) They also have several much lower intensity lines, which are probably too weak to be useful. However, if the pressure in the bulb is increased a little, the other mercury lines become more prominent. This figure compares the wavelenghs from high and low pressure mercury lamps (this figure doesn't show all the wavelengths in the high pressure lamp):

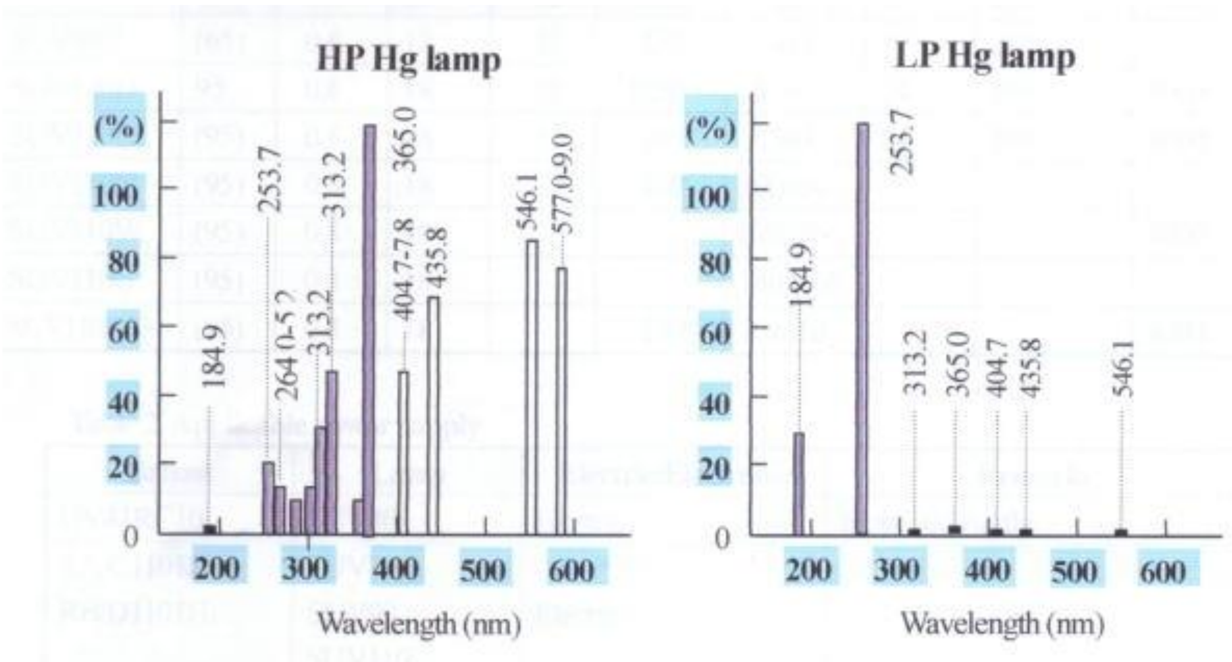


Fig 9. Relative spectral energy distribution of Hg lamps

Source: http://www.senlights.com/lamp/lplamp/lamp.htm

This principle is used in specialized light sources that are sold for calibrating spectrometers. For example:

Ocean Optics HG-1 Calibration Source: USD $553.00
https://oceanoptics.com/product/hg-1/

Here is another option with separate lamp and power supply:

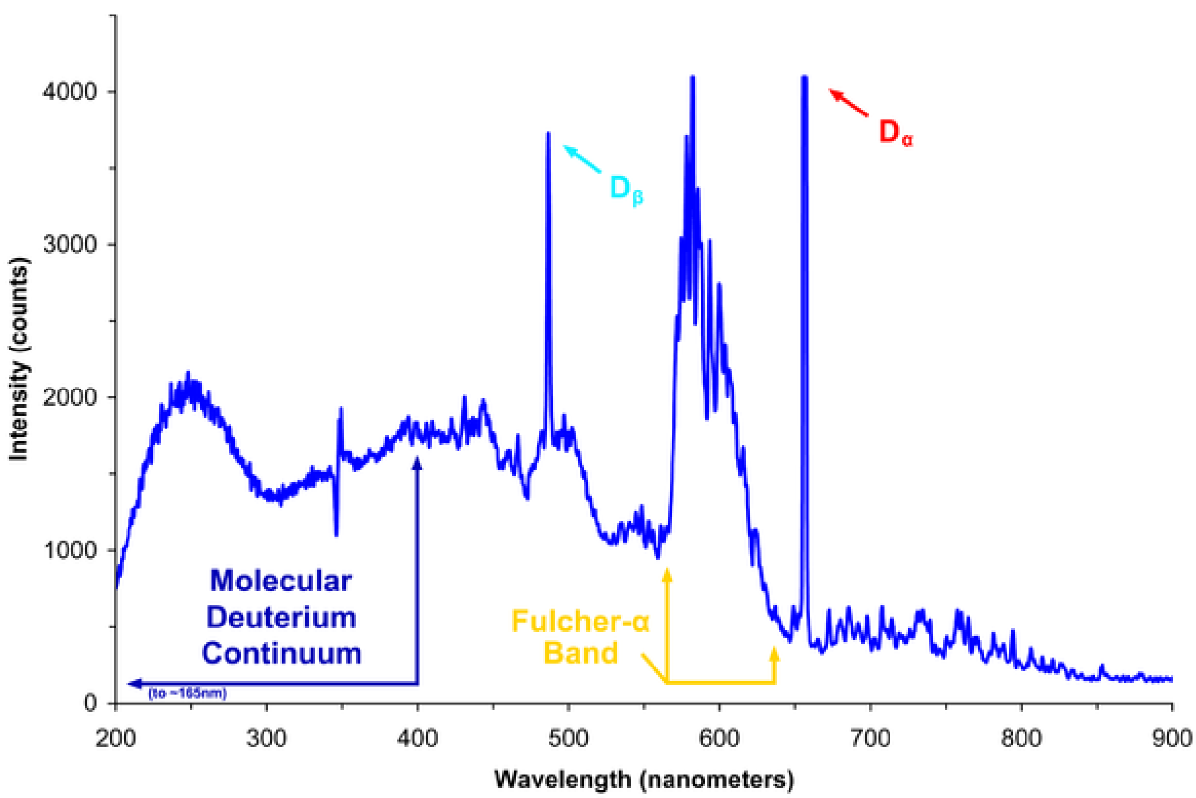
Newport 6035 Spectral Calibration Lamp: USD $232, Lifetime: 5000 hours
Newport Lamp Power Supply 6047: USD $382.00
https://www.newport.com/p/6035

These calibration lamps contain mercury and argon, and in addition to the line at 253.7 nm, also have lines at the following wavelengths in the UV:

253.652 nm
296.728
302.150
313.155
334.148
365.015

The lines at 296.7 or 302.1 nm would probably be close enough to 290 nm to be useful. This kind of light source is too costly for a super-cheap field instrument. As far as I can tell, bulbs like the kind in this calibration source are not commonly sold, except for specialized applications like calibrating spectrophotometers, which means they are not mass produced like the low pressure mercury lamps used for disinfection are. However they might be a good option for a more "deluxe" version.

Another common light source used in UV spectrometers is deuterium lamps. Deuterium is a stable isotope of hydrogen. It is not radioactive, and makes up about 0.02% of all the hydrogen naturally occurring in ocean water. (https://en.wikipedia.org/wiki/Deuterium) These lamps have emission throughout the UV:



Source: https://en.wikipedia.org/wiki/Deuterium_arc_lamp

In the spectral region of interest, the emission doesn't have any big spikes, so it would work well. However, they are fairly expensive, and require a power supply which is also expensive. For example:

Newport 30W Deuterium Lamp: USD $550.00
Newport Power supply for deuterium lamp: USD $1185.00
https://www.newport.com/f/deuterium-lamp-power-supplies

In principle, an inexpensive power supply could be built from scratch, but the lamp itself would still need to be purchased.

Another option for a light source is LEDs. There are LEDs available in the deep UV, however, they are not cheap, for example:

QPhotonics UVTOP240 (240-250nm): $340
QPhotonics UVTOP285 (285-295nm): $175
http://www.qphotonics.com/UVTOP-LEDs/

In general, the longer the wavelength, the cheaper the LED: There are much less expensive LEDs available at longer wavelengths in the UV, for example:

5mm LED - 351nm: $19.99
5mm LED – 361 nm: $3.99
http://www.ledsupply.com/leds/5mm-led-ultra-violet-351nm-15-degree-viewing-angle

These would not be suitable for the wavelengths published in the article. However, they are close to the wavelengths corresponding to the absorbtion maximum of flavokavains (340-350nm). In the article it is stated that the wavelength 290 nm, which corresponds to the maximum of DHM, is preferable to the FK max wavelength because there are other substances overlapping the FK peak, especially yangonin and DMY, so that the ratio 250/290nm gives better statistics than the 250/350 ratio would. However it is not stated what the statistics at 250/350 actually are, and whether they would be sufficiently favorable to be useful at all, even if they are not optimal. This figure showing the UV absorbstion spectra of kava varieties in ether does suggest that the 250/350 nm ratio could possibly be useful:

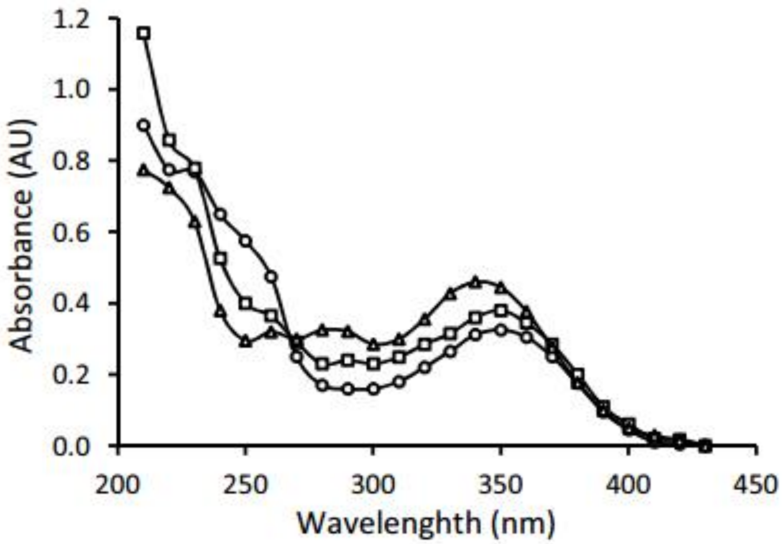


Fig. 5. Typical absorption spectra of a diethyl ether extract of the roots of noble, two-day and wichmannii cultivars. Absorbance spectra of a noble ('Ni Kawa Pia'—circles), a two-day ('Twoday'—squares) and a wichmannii ('Sini Bo'—triangles) were recorded from 210 nm to 430 nm. Absorbances were zeroed against diethyl ether at each wavelength.

So for the least expensive method completely consistent with the method in the paper we would use a low pressure mercury lamp for the 250 nm light, combined with a UV LED for the 290 nm light.

For a much less expensive option, but one that implements a method that is not characterized in the paper, we could use an inexpensive mercury lamp at 250 nm, and an inexpensive LED at 350 nm.

Although LEDs have the advantage of being simple to design electronics for, and have longer lifetimes than the mercury lamps, they have the disadvantage of a much wider bandwidth (approx 10 nm, vs the extremely narrow atomic lines of the mercury lamps). However that might not be a major problem, because the kava extract spectrum is fairly spread out.

Another issue with LEDs is that the wavelength they emit depends on temperature, compared to the mercury lines, which are constant because they depend only on the fundamental physical properties of mercury atoms. (The intensity of LED light also depends on temperature.) So in the case of LEDs, there would need to be a way to either maintain a constant temperature, or compensate for variations in temperature. This would be especially important if there were also a discharge lamp in the same instrument: the LED would need to be shielded from the heat of the lamp (although mercury lamps are very efficient, so there would not be too much heat).

For our "deluxe" model, we could use a medium or high-pressure mercury-argon lamp, or a deuterium lamp.

If we were to use separate light sources, we would not need grating to separate the wavelengths, but since the mercury lamp would require some time to warm up, it would be desirable to have a mechanical means of shutting off the light from it, rather than having to wait 10 minutes when turning it off and on. A way to do that is to place the mercury bulb inside a compartment with and iris that can be opened and closed with a motor. Something like this:

Edmund Optics 25mm Max Aperture Motorizable Iris: USD $75.00
https://www.edmundoptics.com/optomechanics/irises-apertures/iris-diaphragms/high-performance-motorizable-irises/34292/

A motor and motor controller would also be needed, maybe something like:

9g Micro Servo Motor (4.8V), USD $3.63
http://www.robotshop.com/en/9g-micro-servo-motor-4-8v.html

Maybe a cheaper alternative to an iris could be a simple cover that could be swung out of the way of an aperture with a motor. However, the optical iris has the advantage of being designed to be prevent light from leaking out.

A setup using a deuterium or medium or high pressure mercury lamp would require a way to separate the correct wavelength: either a dispersive element such as a diffraction grating, or a pair of narrow band UV filters.

Here are some typical prices for dispersive elements. This needs to be designed for the UV, so cheap diffraction gratings can't be used:

UV Reflective Holographic Grating, 600/mm, 12.7 mm x 12.7 mm x 6 mm: USD $83.75
UV Transmission Grating, 600 Grooves/mm, 22.0° Groove Angle, 12.7 mm x 12.7 mm: USD $89.50
https://www.thorlabs.com/navigation.cfm?guide_id=9

Photodiodes are frequently used as detectors. The photodiode selected needs to be compatible with UVC. For example:

SGLUX SG01S-C18 PHOTODIODE, SIC UV-C: USD $88.03, Wavelength of peak sensitivity: 270 nm:
http://www.newark.com/sglux/sg01s-c18/photodiode-sic-uv-c-a-0-06mm2/dp/53W9989

For a design with a dispersive element, we would need 2 photodiodes, because it would be desirable to have no moving parts, so we don't want to try to rotate the grating or move the detector, or something.

To control the instrument and collect data, we need some kind of microcontroller like a Raspberry Pi or an Arduino.

Arduino Uno microcontroller: USD $24.95
https://store-usa.arduino.cc/products/a000066

Raspberry Pi 3 - Model B - ARMv8 with 1G RAM: USD $39.95
https://www.adafruit.com/products/3055

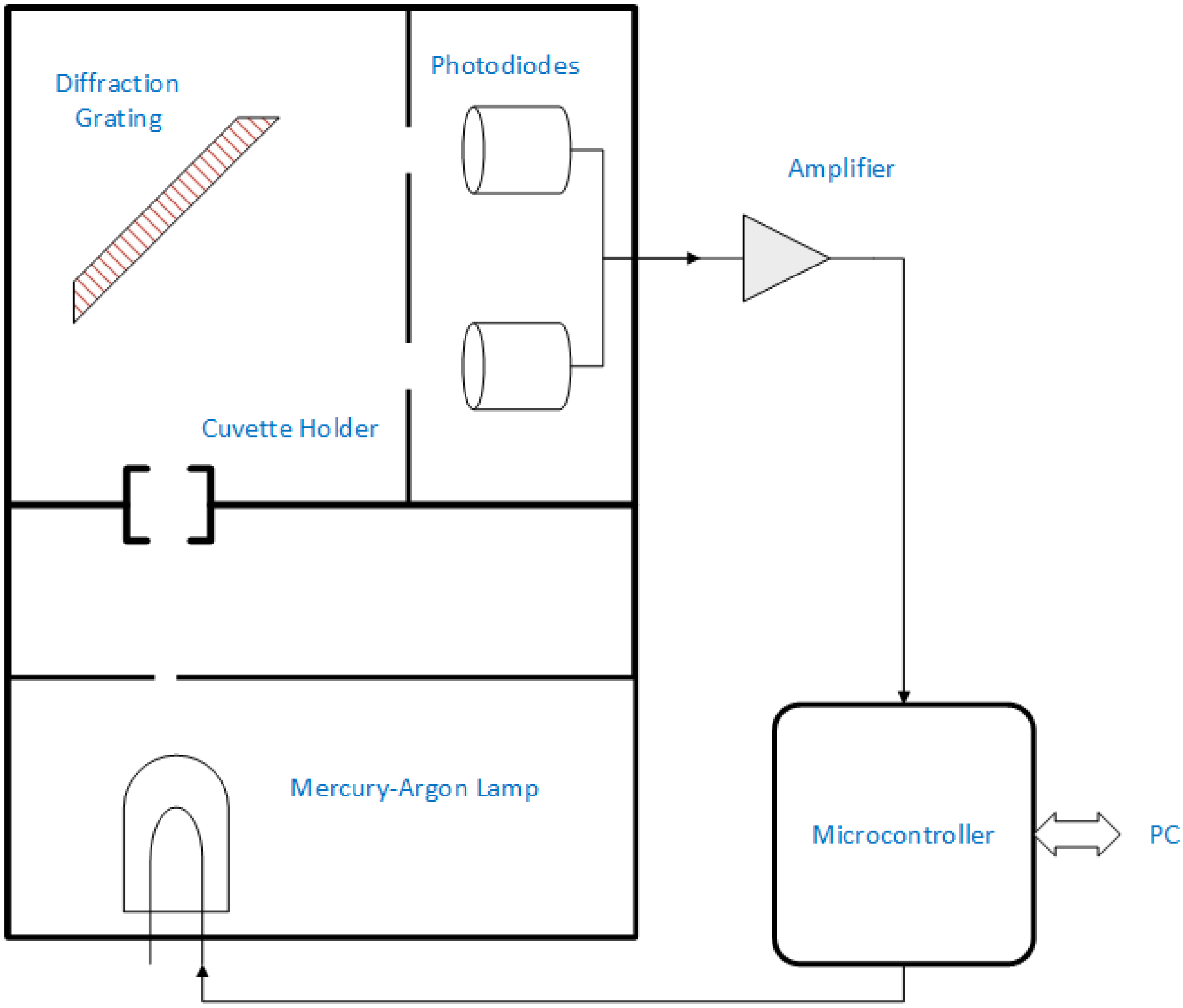
Both the Arduino and Raspberry Pi can be connected directly to a computer or smart phone via USB. The Raspberry Pi is a full blown microprocessor itself, so might be a better choice so an external program would not need to be used. Either of them are very inexpensive, and would be the least of our worries regarding the materials cost of this instrument.

A few additional electronic parts would be needed to control the lamps, and to amplify the signal from the photodiode, and a power supply. They would be pretty inexpensive.

So our designs might looks something like the following:

1. "Deluxe" model. Medium pressure Mercury-Argon lamp with diffraction grating.
   Approximate cost of materials: USD $1100

Schematic drawing of "deluxe model":



2. "Midline" model. 250 nm Low pressure mercury lamp with 290 nm LED. Approximate cost of materials: $500.
3. "Economy" model. 250 nm low pressure mercury lamp with 350 nm LED. Approx cost of materials: $250.

Schematic drawing of 2 and 3: