respectively. Some time after initiation of infusion the rate of entry of drug into each compartment is equal to the rate of exit, *i.e.*, $dX_c/dt = 0$ and $dX_T/dt = 0$. After attainment of this steady-state condition (infusion equilibrium), then it follows from Eqs. 1*a* and 2*a* that

$$(X_c)_{\text{inf. eq.}} = k_0/k_{el} \qquad \text{(Eq. 3}a\text{)}$$

and

$$(X_T)_{\text{inf. eq.}} = k_{12}\, k_0/k_{21}\, k_{el} \qquad \text{(Eq. 4}a\text{)}$$

During the course of integration of Eqs. 1*a* and 2*a* to determine X_c and X_T explicitly, the constants α and β are defined so that

$$\alpha\beta = k_{21}\, k_{el} \qquad \text{(Eq. 5}a\text{)}$$

and

$$\alpha + \beta = k_{el} + k_{12} + k_{21} \qquad \text{(Eq. 6}a\text{)}$$

Substituting Eq. 5*a* in Eqs. 3*a* and 4*a* yields Eqs. 1 and 2 in the text.

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Ultrasonic Extraction of *Cassia acutifolia*

INDUKUMAR C. PATEL and DONALD M. SKAUEN

Abstract □ *Cassia acutifolia* has been extracted using ultrasonic energy in the form of a powerful step-horn converter. The amount of aglycones extracted by this means was compared with aglycones extracted by a standard infusion method. Under similar conditions ultrasonic extraction was more rapid and produced more aglycones than the infusion method. The amount of heat applied has an important effect in the extraction of *Cassia acutifolia*.

Keyphrases □ Ultrasonic extraction—*Cassia acutifolia* □ Extraction comparison—boiling water, ultrasonic □ Temperature effect—*Cassia acutifolia* extraction

Under appropriate conditions, ultrasound has been shown to be very effective in extracting various principles from biological cells. In the majority of the studies reported in the pharmaceutical literature, low power, tank type generators were used (1–4). Ovadia and Skauen (5) reported their experiences with a step-horn ultrasonic generator of high power in extraction experiments with *Cinchona*, *Cephaëlis*, and *Pilocarpus* species. Morrison and Woodford (6) utilized a similar ultrasonic probe for an aqueous extraction of senna pericarps.

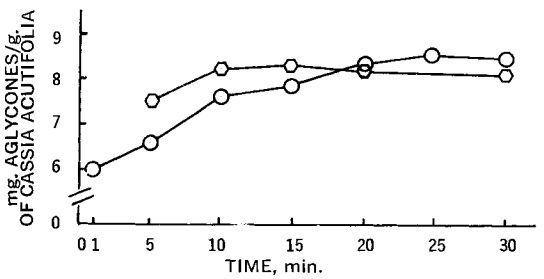

Figure 1—*Comparison of ultrasonic extraction without boiling water and infusion extraction with boiling water. Key:* ○, *ultrasonic extraction (without boiling water);* ○, *infusion extraction (boiling water).*

This investigation was conducted to determine the effects of a more powerful step-horn converter[1] on the extraction of *Cassia acutifolia*,[2] and to compare those results with a standard infusion technique.

EXPERIMENTAL

Ten-gram samples of powdered *Cassia acutifolia*, No. 40 mesh, were weighed and placed into 240-ml. polyethylene containers. One hundred milliliters of water was added and the drug macerated for 10 min. Fifty milliliters of water, brought to pH 8 with 1 *N* NaOH, was added and the samples insonated for the required periods of time. The mixture was then cooled, made up to 300 ml. with water, filtered, and the residue washed with 50 ml. of water in divided portions.

Ten milliliters of the combined filtrate was used to determine the amount of aglycones present after hydrolysis of the extracted glycosides. This assay method was a modification of the method introduced by Fairbairn and Michaels (7).

The glycosides extracted without ultrasound were treated in a similar manner using boiling water and eliminating the maceration step.

When it became necessary to compare ultrasonic extraction without maceration with similar infusion extraction, the general pro-

[1] Model S-125 Sonifier, Branson Sonic Power Co., Danbury, Conn.

[2] Courtesy of Meer Corp., New York, N. Y. 10036

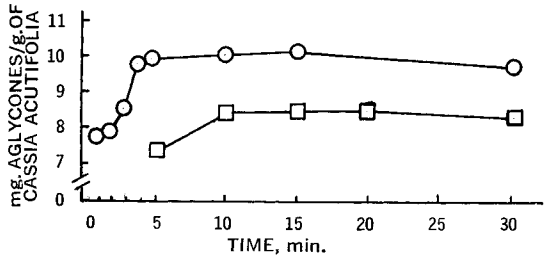

Figure 2—*Comparison of ultrasonic extraction with boiling water and infusion extraction with boiling water. Key:* ○, *ultrasonic extraction (boiling water);* □, *infusion extraction (boiling water).*

cedure described above was used. In place of the maceration step, boiling water was added and insonation started immediately. At the end of each experiment the samples were quickly cooled to 25° and then assayed.

RESULTS

The amount of aglycones extracted by ultrasonics without boiling water, compared with a boiling water infusion technique is shown in Fig. 1. Over a 30-min. period total extractive, as measured by the assay method used, was about the same. Figure 2 illustrates the result when boiling water is used for both ultrasonic and infusion extraction. This is probably a more valid comparison than the results depicted in Fig. 1. In this instance, about 3 min. of ultrasonic irradiation extracts the same quantity of material as 10 min. of infusion. It should also be noted that maximum extraction occurs at about 5 min. with ultrasonics and at about 10 min. with infusion. In addition, nearly 17% more aglycones are extracted by ultrasonics than by infusion. During the 30-min. period there is no significant amount of degradation by either ultrasound or boiling water. If the results in Figs. 1 and 2 are compared, it is evident that

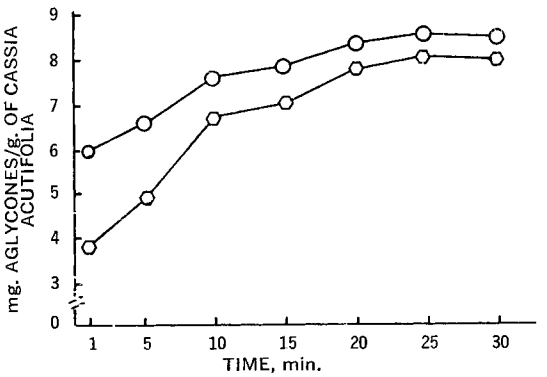

Figure 3—*Ultrasonic extraction with and without temperature control. Key:* ○, *without temperature control;* ○, *with temperature control.*

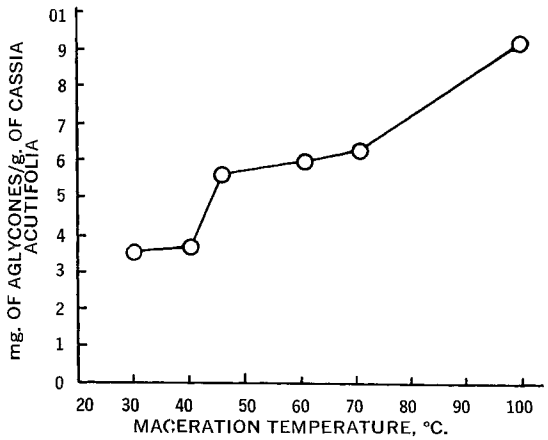

Figure 4—*Effect of maceration temperature upon extraction with identical 1-min. exposures at maximum ultrasonic intensity.*

boiling water is an important factor in determining the rate and extent of ultrasonic extraction.

An additional temperature effect is noted in Fig. 3. In this experiment the temperature of the insonated mixture was allowed to increase at will in one instance while the temperature was controlled by immersion in an ice bath in the other. After 30 min. the temperature of the mixture reached 86° in the uncontrolled but rose to only 40° in the controlled mixture. As one would expect increased temperatures favor extraction of aglycones under the conditions of this experiment.

The effect of change of initial maceration temperature while keeping insonation time and maceration time constant is shown in Fig. 4. In this series of experiments, after each sample was macerated for 10 min., it was cooled to 20° before insonation. In every instance the final temperature after one minute irradiation was 23°. This suggests that the ultrasonic energy input was constant and that heat energy plays a dominant role in extraction of *Cassia acutifolia* aglycones.

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