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Revista de Biología Tropical, vol. 60, núm. 2, junio, 2012, pp. 881-891

Universidad de Costa Rica
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Available in: http://www.redalyc.org/articulo.oa?id=44923872029
In vitro antimalarial activity of extracts of some plants from a biological reserve in Costa Rica

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Received 27-V-2011. Corrected 20-IX-2011. Accepted 21-X-2011.

Abstract: Treatment with the usual antimalarial drugs, have induced parasite resistance, reinforcing the need to finding natural antimalarial components that would be found on plants from the forest. Therefore, we decided to look for these components in Costa Rican plants from a protected forest area. Fresh and dry extracts of roots, bark, leaves, flowers and fruits of 25 plants from a biological reserve in Costa Rica, Reserva Biológica Alberto Manuel Brenes (REBAMB), were studied in vitro for the presence of substances with antimalarial activity. By studying the inhibition of P. berghei schizogony, we assessed the antimalarial activity of several plant extracts: Aphelandra aurantiaca, A. tridentata (Acanthaceae); Xanthosoma undipes (Araceae); Iriartea deltoidea (Arecaceae); Neurolaena lobata (Asteraceae); Neurolea phenotis, Pterocarpus hayessii, Lonchocarpus pentaphyllus (Fabaceae); Nectandra membranacea, Persea povedae, Cinamomum chavarrianum (Lauraceae); Hampea appendiculata (Malvaceae); Ruaega glabra, Guarea glabra (Meliaceae); Psidium guajava (Myrtaceae); Bocconia frutescens (Papaveraceae); Piper friedrichsthalii (Piperaceae); Clematis dioica (Ranunculaceae); Prunus annularis (Rosaceae); Siparuna thecaphora (Siparunaceae); Solanum arboresum, Witheringia solanacea (Solanaceae); Ticodendrum incognitum (Ticodendraceae); Helioanthera appendiculata (Tiliaceae) and Myriocarpa longipes (Urticaceae). We used different parts of the plants as well as fresh and dried extracts for testing IC50. The solid content of the extracts ranged from 1-71.9μg/mL. The fresh extracts showed stronger activity than the dry ones. Since the plants showing the strongest antimalarial activity are very common in Central America, and some similar genera of these plants have shown positives results in South America, we considered important to present these findings for discussion. On the other hand, this is the first systematic study of this kind ever realized in a circumscribed and protected area of Costa Rica. Rev. Biol. Trop. 60 (2): 881-891. Epub 2012 June 01.

Key words: malaria, antimalarial plants, in vitro antimalarial activity, Costa Rican plants, Plasmodium berghei.

Malaria is a very important tropical disease, with a reported human morbidity approaching 300-500 million worldwide and a mortality of 1-2 million deaths per year (WHO 2005, Wrigth 2005). Plasmodium falciparum, the most pathogenic representative of this species, is responsible for the great majority of cases (Tramputz et al. 2003, Batista et al. 2009, Kakkilaya 2008). Confirming this fact, the geographical areas where this species is more frequent, such as Africa, also have the greater incidence of deaths due to malaria infection.

From 1973-1983, Costa Rica implemented strong antimalarial programs, that virtually eradicated the disease and the incidence became near zero for many years (Vargas 2001). The epidemiological control was neglected for the same reason and new infection outbreaks...
appeared again, as a consequence of disordered immigrations and immune deficiencies in segments of the population (AIDS). The outbreaks are not as important as they were in 1991-2000, but are certainly increasing with time (Trejos et al. 2010).

Unfortunately, continuous and frequent treatments with antimalarial drugs, such as chloroquine, have induced parasite resistance (Baird 2004), reinforcing the need for finding more natural antimalarial components. We believe that the best candidates for that would be found on plants from the forest.

Besides, the World Health Organization (WHO), aiming to reduce parasite resistance and to find natural products for this purpose, has promoted research in this area (Simpson 2002, Anthony et al. 2005). Quinine was the first natural drug found for malaria treatment, but because of its high toxicity, its use is limited to only some very qualified cases (WHO 2010). For \( P. \text{falciparum} \) resistant strains, the alternative treatment actually is the use of artemisin derivatives from plants of the genus \textit{Artemisia}. (Kakkilaya 2008, WHO 2010). Research has continued in laboratories of many developed as well as undeveloped countries (Saxena et al. 2003). Several studies regarding this matter have made important contributions to this subject in the past in Costa Rica (Castro et al. 1996, Chinchilla et al. 1998, 2001, 2003).

While, in Africa and Asia there have been many studies that have reported active substances against \( P. \text{falciparum} \) (Pillay et al. 2008, Soh & Benoit-Vical 2007). In Latin-America most of the studies came from South America (Krettli et al. 2001, Botsaris 2007, Valadeu et al. 2009 among others) and very few from Central America (Kohler et al. 2002, Franssen et al. 1997); we believe that our study represents a new contribution to this scientific area.

WHO and OPS (Organización Panamericana de la Salud) recommend, as an official model for research with antimalarial components, the use of \textit{Plasmodium berghei} strains (Ramesar et al. 2008).

Based on the previous knowledge, we decided to perform a more integral study of Costa Rican plants for antimalarial activity. We choose to work in a more protected and less disturbed forest area called “Reserva Biológica Alberto Manuel Brenes” (REBAMB).

This study have three fundamental objectives: 1) Reveal the natural diversity present in REBAMB, 2) Demonstrate the importance of our biodiversity in ethnobotany, especially concerning the treatment of important diseases, such as malaria, and finally, 3) disseminate our studies, in an attempt to help the discovery of new drugs that could improve human health.

**MATERIAL AND METHODS**

**Plants:** A total of 25 different plants (Table 1) were collected from October 2007-December 2008 in the biological reserve, previously mentioned (REBAMB), owned by the University of Costa Rica. This reserve is located 42km Northeast from San Ramón, (10°13’49” N - 84°36’10” W), Alajuela, Costa Rica, with an altitude that varies from 600-1 640 meters above sea level, and an average temperature of 21°C, a relative humidity of 98% and rainfall of 3 461mm per year, thus representing a variety of climates and ecological niches (Sánchez 2000).

Plants were selected according to previous works (Sittenfeld et al. 1999, Chinchilla et al. 2008) that showed that extracts obtained from insects feeding from certain plants, had antimalarial activity. Identification and selection of those host families and species was definitive in choosing the plants for this study.

All the plants were identified by an expert botanist, who based his findings on previous publications (Gómez-Laurito & Ortíz 2004, Barrantes 2004), the geographical location was established with the help of a GPS. All the fresh material collected, was carefully labeled and stored at our herbarium in UCIMED. A photographic register and phenologic analysis was performed for all plants directly in the field.

In all cases, the samples obtained consisted of bark, roots, young and mature leaves, as well as flowers and ripe or unripe fruits. All these materials were placed in individual
plastic bags and transported in a cold container to the laboratory.

Each part of the plant was further divided into two portions: one was kept as fresh material, while the other was dried for subsequent analysis.

**Preparation of extracts:** The fresh material coming from all parts of the plants was carefully washed and then finely chopped; the other portion was dried and prepared as a coarse powder in order to ease extraction. For screening purposes, we used 15g of fresh or 10g of dried material. They were placed in separate 250mL amber bottles, and then extracted with 100mL of 70% ethanol for a week at room temperature, with occasional agitation. These extracts, were vacuum filtered through a Buchner funnel using Whatman 1 paper and then concentrated at 40°C with a rotary evaporator (Buchi R-114); this procedure completely eliminated ethanol.

**In vitro antimalarial assay:**

- Parasite strain: A *P. berghei* strain (NK 65) obtained from American Type Culture Collection (ATCC) was used to assess the antimalarial activity of the extracts. This strain was kept alive by weekly

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**TABLE 1**

Families and species of plants from the REBAMB with antimalarial activity

| Family         | Species                                      | Actividad*     |
|----------------|----------------------------------------------|----------------|
| Acanthaceae    | *Aphelandra aurantiaca* (Scheidw.) Lindl.    | Inactive       |
| Acanthaceae    | *Aphelandra tridentata* Hems. Laura Martínez | Active         |
| Araceae        | *Xanthosoma undipes* (K. Koch & C.D. Bouché) | Inactive       |
| Arecaeae       | *Iriartea deltoidea* Ruiz & Pav.             | Inactive       |
| Asteraceae     | *Neurolela lobata* (L.) Cass. Laura Martínez | VERY ACTIVE    |
| Fabaceae       | *Senna pallida* (Britton & Rose) H.S. Irwin & | Active         |
|                | Barneby Laura Martínez 33.                   |                |
| Fabaceae       | *Pterocarpus hayesii* Hems. Laura Martínez 12.| Inactive       |
| Fabaceae       | *Lonchocarpus pentaphyllus* (Poir.) Kunth ex | Inactive       |
|                | DC. Laura Martínez 24.                       |                |
| Lauraceae      | *Nectandra membracea* (Sw.) Griseb.          | Active         |
| Lauraceae      | *Persea povedae* W.C. Burger                   | Active         |
| Lauraceae      | *Cinnamomum chavarrianum* (Hammel) Kosterm.  | Active         |
| Malvaceae      | *Hampea appendiculata* (Donn. Sm.) Standl.    | Very active    |
| Meliaceae      | *Ruagea glabra* Triana & Planch.             | Active         |
| Meliaceae      | *Guarea glabra* Vahl Laura Martínez 26.      | Inactive       |
| Myrtaceae      | *Psidium guajava* L. Laura Martínez 26.      | Very active    |
| Papaveraceae   | *Bocconia frutescens* L. Laura Martínez 2.   | Very active    |
| Piperaceae     | *Piper friederichsthalii* C. DC. Laura Martínez 13. | Inactive       |
| Ranunculaceae  | *Clematis dioica* L. Laura Martínez 11.      | Active         |
| Rosaceae       | *Prunus annularis* Koehne : Laura Martínez 10.| Inactive       |
| Siparunaceae   | *Siparuna thecaphora* (Poepp. & Endl.) A. DC.| Very active    |
|                | Laura Martínez 38.                           |                |
| Solanaceae     | *Solanum arboreum* Dunal Laura Martínez 22.  | Active         |
| Solanaceae     | *Witheringia solanacea* L’Hér. Laura Martínez 30. | Very active   |
| Ticodendraceae | *Ticodendron incognitum* Gómez-Laur. & L.D. Gómez Laura Martínez 8. | Active       |
| Tiliaceae      | *Heliocarpus appendiculatus* Turcz. Laura Martínez 3. | Inactive       |
| Urticaceae     | *Myriocarpa longipes* Liebm. Laura Martínez 9. | Inactive       |

*Very active: less than 5 µg/mL, Active: >5 to 50µg/mL, Weakly active: >50 to 100 µg/mL, Inactive: >100µg/mL.*
re-infection in Swiss mice following the recommendations given by WHO for these type of studies.

- Experimental animals: Male and female mice (Mus musculus Swiss) weighing 22-24g originally obtained from the University of Costa Rica were used through the experiments. The animals were maintained in an air-conditioned environment in the animal house of UCIMED, feeding with standard pet food and drinking water ad libitum. They were caged in groups of 5-10 and all studies were performed in agreement with international rules for laboratory animal use, under the ACCMAL control in Costa Rica.

- Inoculum: Parasitized erythrocytes were obtained from a previously infected mouse by cardiac puncture using heparin as anticoagulant and then diluted in RPMI 1640 medium, supplemented with 10% fetal calf serum plus antibiotics (RPMI 1640). Animals were inoculated by intraperitoneal injection with a blood suspension (0.2 mL) containing 10^6-10^7 parasitized erythrocytes. After 24h infection, mice showing a parasitic presence in blood of ten to 15% of the erythrocytes infected with ring stages, were used in all the in vitro studies.

- In vitro antimalarial assays: We followed general procedures for P. berghei culture and also for testing in vitro antimalarial effect (Ager et al. 1984, Deharo et al. 2000). Briefly, erythrocytes (final cell suspension 1%, v/v, blood/culture medium), from a one day infected mice, suspended in RPMI 1640 medium, were mixed with the intact plant extracts (0.05mL blood and 0.05mL diluted extract per well), the mixture was transferred to plates and then incubated in a candle jar at 37°C for 24h in a low speed shaker (Mini-Shaker 3D Boeco, Germany). For each experiment we used a positive control with chloroquine in standard concentration and a negative control with only culture medium.

To determine the IC_{50} (minimal concentration that inhibits 50% of parasite schizogony), we made serial dilutions of the extract according to the dry weight obtained in each case. After the incubation period, we made blood smears from each well, stained with Giemsa dye, and the number of schizonts was determined by counting at least 500 red blood cells under the microscope’s 100X objective. The percentage of the parasite schizogony inhibition was calculated by the following formula (Deharo et al. 2000):

\[ \text{Schizogony inhibition (\%)} = \frac{\text{schizonts in control} - \text{schizonts with extract}}{\text{schizonts in control}} \times 100 \]

For calculations and statistical analysis the Probit method (Deharo et al. 2000, Diaz et al. 2004) was used. To classify the activity levels of each extract the Rasoanaivo table (1999) was used. Accordingly the term “very active” means a IC50 less than 5µg/mL; active from >5-50µg/mL; “weakly active” from >50-100µg/mL and “inactive” more than 100µg/mL.

RESULTS

The crude alcoholic extracts obtained from the different plant structures of the 25 varieties studied (Table 1) showed some antimalarial activity (Fig. 1). The plants with the highest activity consistently showed it in both fresh and dried material. Not all plant structures showed the antimalarial effect. Figure 2 show the percentages of plants with one, two, three, four or more structures with potential effect against P. berghei.

There were more plants showing antimalarial activity in only one type of structure, (Figs. 2, 3) but three plants showed it in four or more parts. When comparing extracts of fresh and dried plant with antimalarial activity (Fig. 3), no significant differences were found for structures, except in flowers and young leaves where the dry material showed higher antimalarial activity. Root fresh extracts showed more activity as well.
IC50 tests on fresh (Table 2) and dried extracts (Table 3) yielded the results presented in figure 4. Fresh material (Fig. 4A) showed the highest antimalarial activity (“very active”) as compared to the other categories; it was also independent of the part of the plant studied. In contrast, for dry samples (Fig. 4B), the “active” category presented higher values than the others, again regardless of the plant structure studied.

**DISCUSSION**

Several authors have pursued the search for natural products with antimalarial effect in plants in the past and in recent years (Rafatro *et al.* 2005, Ogbonna *et al.* 2008, Pillay *et al.* 2008, Kayser *et al.* 2003). The rationale for such studies is based on the resistance of the parasites to conventional treatment as observed in the case of malaria (Fidock *et al.* 2008).
This resistance began with *P. falciparum* near the ‘60s and today is extremely common, especially in Africa, Central and South America (Bloland 2001). This resistance has also been documented for *P. vivax* (Baird 2004, Anstey *et al*. 2009) the most common species found outside Africa (Wells *et al*. 2010) and in Costa Rica, were reports account for 95-98% of the cases (Vargas 2001).

Malaria parasites also exhibit resistance to Fansidar, a treatment involving Sulfadoxine and Pyrimethamine, that act inhibiting the formation of nucleic acids (Bloland 2001, Hastings 2004, Kakkilaya 2008).

Based on the foregoing, we started in Costa Rica the search for antimalarial components in plants, as previously documented (Chinchilla *et al*. 1998, 2001, Castro *et al*. 1996).

In conducting this research, we took into account not only the traditional observations on the treatment of malaria and its symptoms, but also the findings of a previous study.
TABLE 2

*In vitro* activity ([IC₅₀], µg/mL) on *P. berghei* of plant fresh extracts

| Species            | B     | F     | UF    | RF    | YL    | ML    | R     |
|--------------------|-------|-------|-------|-------|-------|-------|-------|
| *A. tridentata*    | 4.9   |       |       |       |       |       | 25.1  |
| *B. frutescens*    | 5.9   | 2.8   | 2.4   | 4.6   | 15.2  | 2.2   | 2.6   |
| *H. appendiculata* |       |       |       |       |       |       | 3.9   |
| *N. membranacea*   | 71.9  | 2.2   |       |       | 10.7  | 0.8   | 3.2   |
| *N. lobata*        |       |       |       |       |       |       | 4.1   |
| *P. povedae*       |       |       |       |       |       |       | 9.7   |
| *P. guajava*       |       |       |       | 5.3   |       |       | 8.2   |
| *S. thecaphora*    | 2     | 1     |       | 3.9   |       |       | 50.8  |
| *S. papillosa*     |       |       |       |       |       |       | 0.9   |
| *T. incognitum*    |       |       |       |       |       | 3.3   | 9.1   |
| *W. solanacea*     |       |       |       |       |       |       | 1.3   |

B: bark, F: flowers, UF: unripe fruit, RF: ripe fruit, YL: young leaves, ML: mature leaves, R: root.

**Fig. 4.** Relationship between the strength of antimalarial activity and plant parts studied.
(Chinchilla et al. 2008), in which, antimalarial activity was found in extracts of certain arthropods, especially those that feed on plants during any stage of its life cycle. The plants found as a feeding source of these insects, guided us in choosing species or similar families as the ones studied in this investigation. This selection system led us to obtain 60% positivity in the 25 plants tested.

Very few papers in other countries mention plants with higher antimalarial activity than the ones found in this work. It could be explained by the fact that these plants are characteristically from Central America (Jenett-Siems et al. 1999), and no other researchers have done any work with them.

_H. appendiculata_ is found only in Panama, Honduras and Costa Rica (Tropicos 2010) and _T. incognitum_ is a recently classified plant that has not been tested for antiparasitic activity. _S. thecaphora, N. membranaceae_ and _B. frutescens_ have a greater distribution in the Americas, but were not found in any other places (Tropicos 2010). In Africa and Asia there has been an intense and enthusiastic search for active compounds against _P. falciparum_ especially (Aderounmu 2002, Mariath et al. 2009, Titanji et al. 2008); the opposite is true in America where many of the studies come from South America (Krettli et al. 2001, Rodríguez-Pérez et al. 2006, Batista et al. 2009, Valadeau et al. 2009 among others) and very few from Central America (Franssen 1997, Kohler et al. 2002). Antimalarial components have been found in _S. andina, S. pauciflora, S. tonduziana_ and _S. aspera_, but not in _S. thecaphora_. The present study represents an important contribution to this field since the data obtained, together with that already reported, has shown to be inedited.

Most of the studies mentioned, have focused their attention in just a few parts of the plant, but we studied every plant structure, included bark, roots, leaves and fruits in order to optimize the results.

Almost every one of the studies referred before used dried material for extraction. Since the traditional way of using plants for healing is by using fresh material (Blair & Madrigal 2005, Togola et al. 2005) we included this modality as part of our research. Shows that the activity in different structures of the plant was very similar independently of the use of the dry or fresh extract. However, when analyzing the potency of IC50, the fresh material showed, except for bark and mature leaves, a dominance of the condition “very active” over “active”. The opposite is true for dry extracts; it can be deducted that although the antimalarial activity was detectable in both types of extracts, the potency of this activity appears to decrease by drying the structure. The implication of this observation concludes that if only dry samples were to be studied, some plants with antimalarial activity could be missed.

Since this study was performed in a biological reserve, there is a guarantee for the permanence, for many years, of plants with active components against malaria. In addition, all samples were collected in a fairly restricted area, which reduces the risk of changes due to external factors such as climate, soil type and other (Martin 2001). Factors such as stage of development of the plant and the presence of arthropods, also might affect the data, since the plant needs to synthesize new metabolites in order to defend from them (Coley & Barone 1996). These metabolites could also be active against malaria parasites, but this will be the subject of analysis in other publications.

This work seeks to offer a contribution to Ethnobotany applied to Medical Sciences in Costa Rica, as has been done in many other countries (Martin 2001). Studies in progress are being made for identifying the chemical component(s) responsible for the antimalarial effect of the plant extracts.

**ACKNOWLEDGMENTS**

This study was supported in part by a grant (Proyect Forinves 18) of the Consejo Nacional para Investigaciones Científicas y Tecnológicas (CONICIT), Research Department of the Universidad de Ciencias Médicas (UCIMED) and Centro Regional de Occidente, Universidad de Costa Rica. Special thanks to Laura...
El tratamiento con las drogas antimaláricas de uso común han inducido resistencia por parte del parásito, lo que obliga a buscar en las plantas de los bosques, componentes naturales con actividad en contra de esta enfermedad. Por lo tanto, decidimos buscar dichos componentes en plantas de una Reserva Forestal de Costa Rica. Extractos tanto frescos como secos de raíz, corteza, hojas, flores y frutos, de 25 plantas de la Reserva Biológica Alberto Manuel Brenes (REBAMB), fueron estudiados in vitro en busca de sustancias con actividad antimalárica. Las plantas estudiadas fueron: Aphelandra aurantiaca, A. tridentata (Acanthaceae); Xanthosoma undipes (Araceae); Iriartea deltoidea (Arecaceae); Neura laena lobata (Asteraceae); Senna papillosa, Pterocarpus hayessii, Lonchocarpus pentaphyllus (Fabaceae); Nectandra membranacea, Persea longipes (Lauraceae); Myriocarpa medica (Piperaceae); Piper friedrichsthalii (Tiliaceae) y Heliocarpus appendiculatus (Ticodendraceae); Ticodendrum incognitum (Ticodendraceae); Solanum glabra, Guarea glabra (Meliaceae) y Psidium guajava (Myrtaceae). Los extractos frescos proporcionaron mayor actividad antimalárica. Las plantas que presentaron mayor actividad son muy comunes en la Reserva Biológica Alberto Manuel Brenes: Ruagea glabra, Xanthosoma undipes (Araceae); Neurolaena lobata y Solanum glabra (Solanaceae); Heliocarpus appendiculatus (Ticodendraceae) y Myriocarpa medica (Piperaceae). A. tridentata y Heliocarpus appendiculatus han sido utilizados en medicina tradicional. Los extractos secos mostraron menor actividad antimalárica. Las plantas que presentaron mayor actividad son muy comunes en Centroamérica y algunos géneros similares, aunque no las mismas especies, han sido encontrados en otras partes de Centroamérica. Por esta razón consideramos importante estos resultados como información y materia de discusión en este tema. Además este es el primer estudio sistémico de esta naturaleza realizado en un área boscosa circunscripta y protegida de Costa Rica.

Palabras clave: malaria, antimaláricos, in vitro, plantas, Costa Rica, Plasmodium berghei.

RESUMEN

El tratamiento con las drogas antimaláricas de uso común han inducido resistencia por parte del parásito, lo que obliga a buscar en las plantas de los bosques, componentes naturales con actividad en contra de esta enfermedad. Por lo tanto, decidimos buscar dichos componentes en plantas de una Reserva Forestal de Costa Rica. Extractos tanto frescos como secos de raíz, corteza, hojas, flores y frutos, de 25 plantas de la Reserva Biológica Alberto Manuel Brenes (REBAMB), fueron estudiados in vitro en busca de sustancias con actividad antimalárica. Las plantas estudiadas fueron: Aphelandra aurantiaca, A. tridentata (Acanthaceae); Xanthosoma undipes (Araceae); Iriartea deltoidea (Arecaceae); Neura laena lobata (Asteraceae); Senna papillosa, Pterocarpus hayessii, Lonchocarpus pentaphyllus (Fabaceae); Nectandra membranacea, Persea longipes (Lauraceae); Myriocarpa medica (Piperaceae); Piper friedrichsthalii (Tiliaceae) y Heliocarpus appendiculatus (Ticodendraceae); Ticodendrum incognitum (Ticodendraceae); Solanum glabra, Guarea glabra (Meliaceae) y Psidium guajava (Myrtaceae). Los extractos frescos proporcionaron mayor actividad antimalárica. Las plantas que presentaron mayor actividad son muy comunes en la Reserva Biológica Alberto Manuel Brenes: Ruagea glabra, Xanthosoma undipes (Araceae); Neurolaena lobata y Solanum glabra (Solanaceae); Heliocarpus appendiculatus (Ticodendraceae) y Myriocarpa medica (Piperaceae). A. tridentata y Heliocarpus appendiculatus han sido utilizados en medicina tradicional. Los extractos secos mostraron menor actividad antimalárica. Las plantas que presentaron mayor actividad son muy comunes en Centroamérica y algunos géneros similares, aunque no las mismas especies, han sido encontrados en otras partes de Centroamérica. Por esta razón consideramos importante estos resultados como información y materia de discusión en este tema. Además este es el primer estudio sistémico de esta naturaleza realizado en un área boscosa circunscripta y protegida de Costa Rica.

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