

Taxonomy of *Puccinia* species causing rust diseases on sugarcane*

Eric V. Virtudazo¹⁾, Hidenobu Nojima²⁾ and Makoto Kakishima^{1)**}

¹⁾ Institute of Agriculture and Forestry, University of Tsukuba, Tsukuba, Ibaraki 305–8572, Japan

²⁾ Kagoshima Agricultural Experiment Station, Kamifukumoto-cho, Kagoshima-shi, Kagoshima 891–0116, Japan

Accepted for publication 25 December 2000

A taxonomic revision of *Puccinia* species causing rust diseases on sugarcane was conducted to clarify their morphological characteristics. Specimens including previously reported species, *Puccinia melanocephala*, *P. kuehnii* and *Puccinia* sp. sensu Muta, 1987, were collected in Japan and the Philippines and borrowed from various herbaria worldwide. Morphological characteristics of these specimens were examined under light and scanning electron microscopes. Comparative morphological studies of the specimens showed that rust fungi infecting sugarcane could be classified into two species, *Puccinia melanocephala* and *P. kuehnii*. *Puccinia* sp. sensu Muta was morphologically identical with *P. kuehnii*. Results of this study corroborate previous phylogenetic analysis results of D1/D2 regions of LSU rDNA gene.

Key Words—*Puccinia kuehnii*; *Puccinia melanocephala*; sugarcane rusts; taxonomy; Uredinales.

Puccinia melanocephala Syd. et P. Syd. and *Puccinia kuehnii* Butler are reported to cause rust diseases on sugarcane (Cummins and Hiratsuka, 1983; Hiratsuka and Kaneko, 1983; Sivanesan and Waller, 1986; Ryan and Egan, 1989). These two species have been reported in various parts of the world where sugarcane is cultivated. In addition, Muta (1987) reported *Puccinia* sp. as an unidentified rust pathogen on sugarcane in the Nansei Islands, Kagoshima Pref., Japan.

Puccinia kuehnii was first described as *Uromyces kuehnii* Krueger because of the presence of apically thick-walled urediniospores that were apparently mistaken as teliospores. It was later renamed as *Uredo kuehnii* (Krueger) Wakker et Went, since the telial stage was not found and the apically-thick walled spores were proven to be urediniospores (Sydow et al., 1906a; Ito, 1909; Butler, 1914; Ryan and Egan, 1989). Butler (1914) found teliospores of this fungus on *Saccharum spontaneum* L. and named the species as *Puccinia kuehnii*. Most of subsequent descriptions of the telial stage of *P. kuehnii* were cited from his description because no teliospore was found in either sugarcane or the other grass hosts (Laundon and Waterson, 1964; Cummins, 1953, 1971; Sivanesan and Waller, 1986; Ryan and Egan, 1989). Although the telial stage of *P. kuehnii* was reported by Hiratsuka (1958), Teng and Ou (1937, cited by Tai, 1947), Tai (1947), Patel et al. (1950) and Chona and Munjal (1950), these descriptions were inconsistent with those of Butler (1914) and similar to descriptions of *P.*

miscanthi Miura or *P. melanocephala*. In 1986, Hennen found teliospores on specimens collected in Taiwan. They were different from those described by Butler (1914) in color of telia and size of teliospores. However, he reported them as mature teliospores of *P. kuehnii* and suggested that Butler (1914) observed immature teliospores (Hennen, 1986). In 1987, Muta also found teliospores similar to those described by Hennen (1986) on sugarcane collected in the Nansei Islands and reported them as *Puccinia* sp., because these specimens were different from *P. kuehnii* in the absence of paraphyses in uredinia and telia.

There was also confusion in the naming of *P. melanocephala*, due to an apparent misidentification of the host from which the original description was made. Sydow et al. (1906b) were the first to name it as *P. melanocephala* on *Bambusa* sp., which was later found to be *Erianthus* sp. (Cummins, 1971; Sathe, 1971). When Padwick and Khan (1944) found a rust on *Erianthus rufipilis* (Steud.) Griseb. (= *E. fulvus* Nees ex Stend.), they gave it a different name, *P. erianthi* Padwick et Khan, which became the widely used name for the rust later found causing epidemics in commercial sugarcane. When Cummins (1971) and Sathe (1971) found that the rust described by Sydow et al. (1906b) actually occurs on an *Erianthus* sp., they proposed that it should be named *P. melanocephala*, since this name antedates the name *P. erianthi*, which becomes a nomenclatural duplication. However, misidentification of *P. melanocephala* still occurs in more recent literature such as that of Presley et al. (1978) and other reports cited by Egan (1980). Egan (1980) showed that reports of *P. kuehnii* in Africa and the Americas were in fact *P. melanocephala* based on previous records of sugarcane rusts and the non-suscep-

* Contribution No. 157, Laboratory of Plant Parasitic Mycology, Institute of Agriculture and Forestry, University of Tsukuba

** Corresponding author. E-mail: kaki@sakura.cc.tsukuba.ac.jp

tibility of the sugarcane varieties cultivated in these areas to *P. kuehnii*.

Although recent reviews of rust diseases including sugarcane rusts described the history, distribution, and characteristics of these rusts (Ryan and Egan, 1989; Purdy, 1985), there are still inconsistencies in descriptions of certain morphological characteristics and variations among authors. In view of the lack of comprehensive taxonomic treatment of rust pathogens on sugarcane and the recent report of an unidentified rust from Japan, a taxonomic revision of these sugarcane rust pathogens was considered necessary.

A previous study on the phylogenetic relationships of these sugarcane rusts revealed that sugarcane rusts can be clearly separated into two main phylogenetic groups based on D1/D2 regions of LSU rDNA, although there was considerable divergence in the ITS regions (Virtudazo et al., 2001).

This study was conducted to clarify the taxonomy of the *Puccinia* species causing rust diseases on sugarcane and the taxonomic status of *Puccinia* sp. *sensu* Muta (1987) reported in the Nansei Islands, Kagoshima Pref., Japan.

Materials and Methods

Collections were conducted in sugarcane fields and agricultural experiment stations in Amamiyoshima Is., Kagoshima Pref. in June, 1996, in Okinawa Is., Miyako Is., Ishigaki Is., and Iriomote Is., Okinawa Pref. in December, 1996, and in the provinces of Negros Occidental and Davao del Sur in the Philippines in August, 1996. These collections were dried and kept at the Mycological Herbarium, Institute of Agriculture and Forestry, University of Tsukuba (TSH). Dried herbarium specimens identified as *Puccinia melanocephala* and *P. kuehnii* were borrowed from the National Fungus Collections, United States Department of Agriculture, Beltsville, USA (BPI), the Arthur Herbarium, Purdue University, West Lafayette, USA (PUR), the Herbarium of the Plant Disease Division, Landcare Research, Auckland, New Zealand (PDD), the Rijksherbarium, Leiden, Netherlands (L), Institute of Botany, Jagiellonian University, Krakow, Poland (KRAM), the Mycological Herbarium, Swedish Museum of Natural History, Stockholm, Sweden (S), and from the collections of the Shikoku Agricultural Experiment Station, Japan. Specimens examined are listed in the description of the species.

Morphological characteristics were examined under light and scanning electron microscopes (SEM). Spore dimensions were measured using an Olympus Color Image Analyzer CIA 102. Urediniospores, teliospores, and cross-sections of uredinia and telia were mounted in SEM specimen holders using double adhesive tape and coated with platinum-palladium using a Hitachi Ion Sputter E-1030. Surface structures of uredinia, telia and spores were examined with a Hitachi Scanning Electron Microscope S4200 operating at 15.0 kV.

Results

Uredinia The lesions formed around the uredinia on the specimens examined could be classified into two major types. The first type is generally brown to dark brown, with dark necrotic areas around uredinia, sometimes coalescing to form large necrotic areas with many uredinia. The second type is generally lighter brown, sometimes yellowish to yellow-orange, and with some brown necrotic areas around uredinia.

However, the sugarcane rust specimens cannot be readily distinguished based only on observations of the symptoms in old herbarium specimens, in specimens collected from the field, and in those produced from inoculation experiments (data not shown). Most of the herbarium specimens labeled as *P. melanocephala* were found to have the first type of lesion, while most of the herbarium specimens labeled as *P. kuehnii* had the second type of lesion. The lesions in most of the *P. kuehnii* specimens, which were mostly from very old collections, ranged from pale yellow to yellow-orange. In certain specimens, reddish brown lesions were found and could not be distinguished from those found in most of the *P. melanocephala* specimens. Most of the specimens collected from sugarcane fields in Japan and the Philippines had the second type of lesion, similar to those of specimens labeled as *P. kuehnii*: they were yellow or reddish brown, and sometimes coalesced into large necrotic areas. The remaining specimens had the same type of lesions as herbarium specimens of *P. melanocephala*.

Uredinia observed in the specimens examined could also be grouped into two types based mainly on color and paraphyses. The first type generally were cinnamon-brown to dark brown, mainly hypophyllous and linear, and with abundant paraphyses, which were sometimes more numerous than urediniospores in the uredinia (Fig. 1B). The paraphyses were usually capitate, sometimes spatulate, colorless to golden brown, with walls in the head thicker than in the stipe (Fig. 1C). Uredinia found in most of the herbarium specimens of *P. melanocephala* and some of the specimens collected in Japan and the Philippines were of this type.

The second type of uredinia ranged from orange to yellowish brown, sometimes cinnamon-brown, and distinct paraphyses like those in the first type were absent. Extremely thin-walled, sometimes obovoid or small, but more often irregularly shaped and hyaline paraphyses-like structures were observed in the second type (Fig. 2C, D). Under the SEM, they seemed to occur underneath the urediniospores and could usually be observed only when the urediniospores were removed from the uredinia (Fig. 2B). When urediniospores were still present, they could be seen in the periphery of the uredinia in some specimens. *Puccinia kuehnii* specimens and most of the specimens collected in Japan and the Philippines had this type of uredinia. Specifically, specimens collected from the Nansei Islands, Kagoshima Pref., Japan, where *Puccinia* sp. *sensu* Muta (1987) was reported, could not be distinguished from other specimens having this type of uredinia in characteristics of

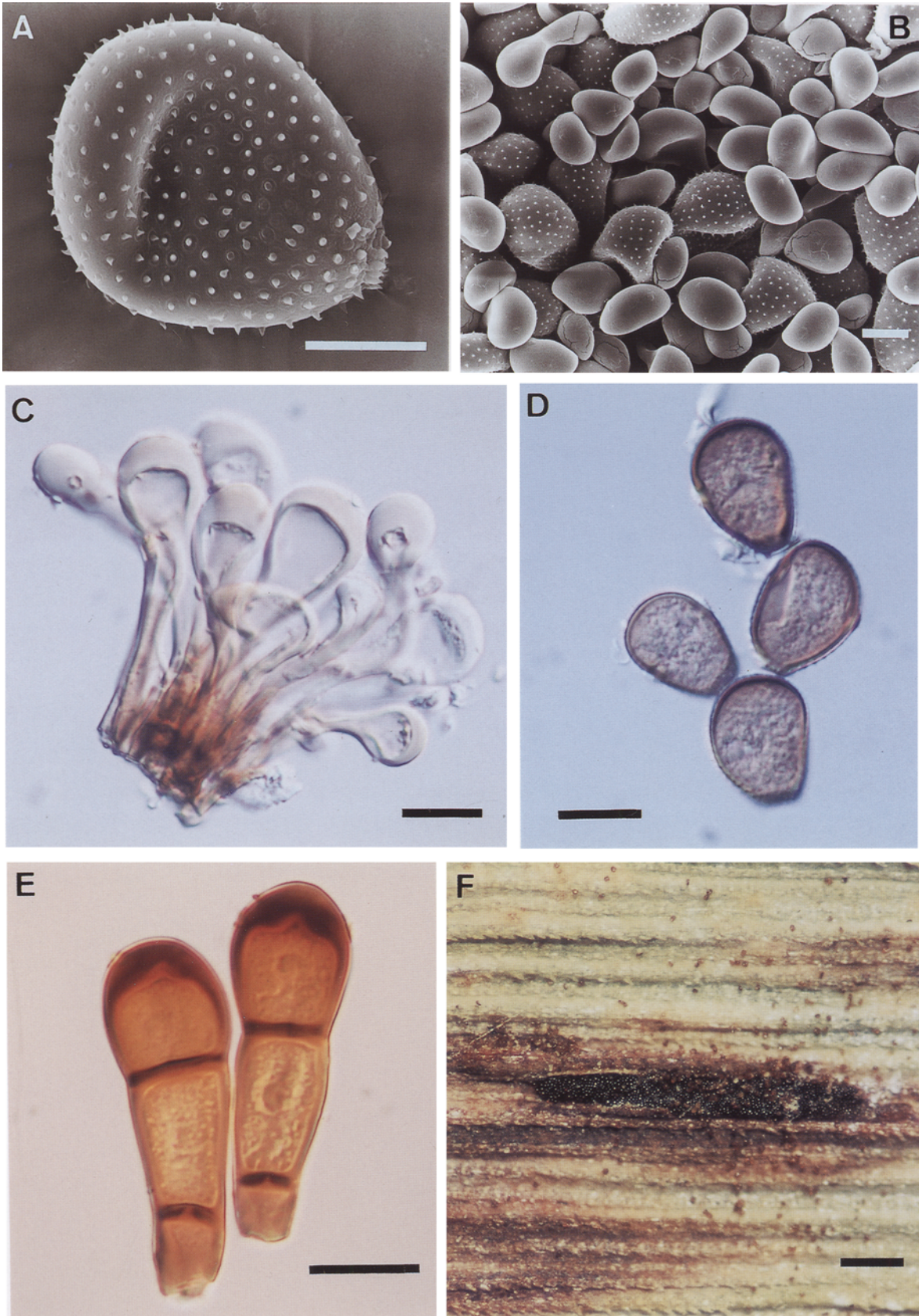


Fig. 1. *Puccinia melanocephala*. A. Urediniospore (SEM), B. Uredinium (SEM) showing abundant paraphyses among urediniospores, C. Paraphyses, D. Urediniospores, E. Teliospores, F. Telium. Scale bars: A, B = 10 μ m; C–E = 20 μ m; F = 0.5 mm.

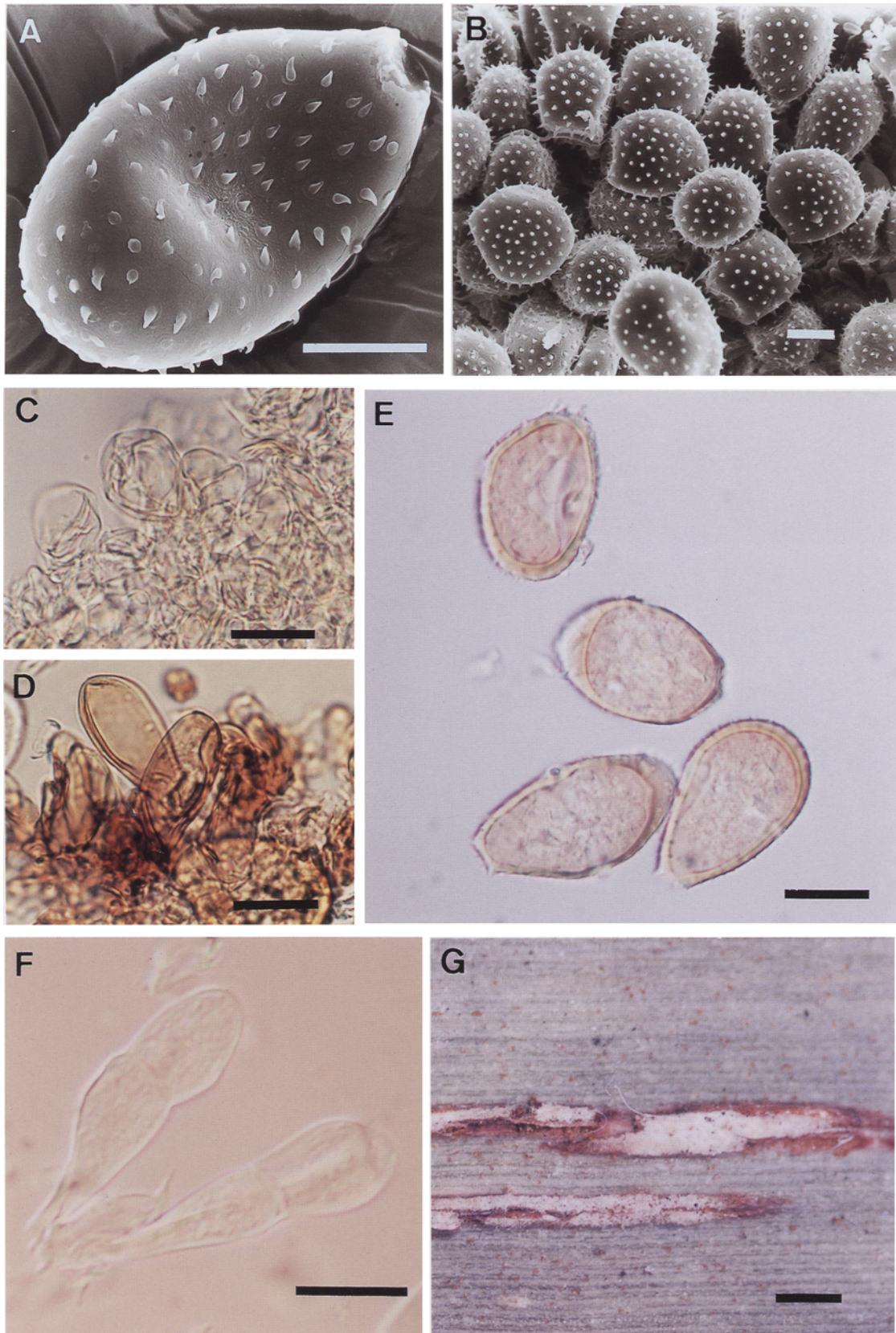


Fig. 2. *Puccinia kuehnii*. A. Urediniospore (SEM), B. Uredinium (SEM), paraphyses not seen, C-D. Paraphyses, E. Urediniospores, F. Teliospores, G. Telia. Scale bars: A, B=10 μ m; C-F=20 μ m; G=0.5 mm.

paraphyses. Furthermore, since the paraphyses were irregular in size and shape, their presence sometimes could not be clearly ascertained.

Urediniospores Based on color and wall thickness of urediniospores, the specimens could be separated into two types. Most of the herbarium specimens of *P. melanocephala* and some specimens collected in Japan and the Philippines had urediniospores that were mostly obovoid, sometimes ellipsoidal, with uniformly thick walls. The spores of this type were cinnamon-brown to dark brown (Fig. 1D). On the other hand, urediniospores of most herbarium specimens of *P. kuehnii* were mostly obovoid or pyriform, sometimes ellipsoidal. Some of their spores had slight to pronounced apical thickening around 5 μm or more, while others had uniformly thick walls. Urediniospores of this type ranged from golden yellow to orange, sometimes cinnamon-brown (Fig. 2E). Urediniospores in most of the specimens collected in Japan and the Philippines were similar to this type in shape, color and wall thickness.

SEM examinations showed that the urediniospore surface ornamentation in the specimens could be distinguished into two types. The first type was observed in urediniospores of most herbarium specimens of *P. melanocephala* and some specimens from Japan and the Philippines. In this type, the spore surface was densely echinulate and the spines were regularly spaced (Fig. 1A) except near the pores, where they tended to be more

closely spaced. Spines at base of the spores in this type also tended to be bigger and more developed than spines in the other parts of the spore. The second type of urediniospore surface ornamentation was observed in most *P. kuehnii* specimens and most of the specimens collected in Japan and the Philippines. In this type, the echinulations were less dense than those found in urediniospores of specimens of the first type and were more or less evenly distributed over the spore surface (Fig. 2A). The spines of this type were also bigger, longer, more pointed and had a wider base than spines of the first type.

In urediniospore size, herbarium specimens of *P. melanocephala* tend to be in the smaller range, while those of *P. kuehnii* in the larger range. Among the specimens collected in Japan and the Philippines, those having characteristics similar to those of herbarium specimens of *P. melanocephala* were in the smaller range, while those having characteristics similar to herbarium specimens of *P. kuehnii* were distributed in the larger range (Fig. 3). However, these size ranges overlap and the specimens could not be separated based on urediniospore size.

Telia and teliospores In specimens producing the telial stage, two types of telia were observed. The first type was found in herbarium specimens of *P. melanocephala* and some specimens collected in Japan and the Philippines, whose uredinial stage was morphologically similar

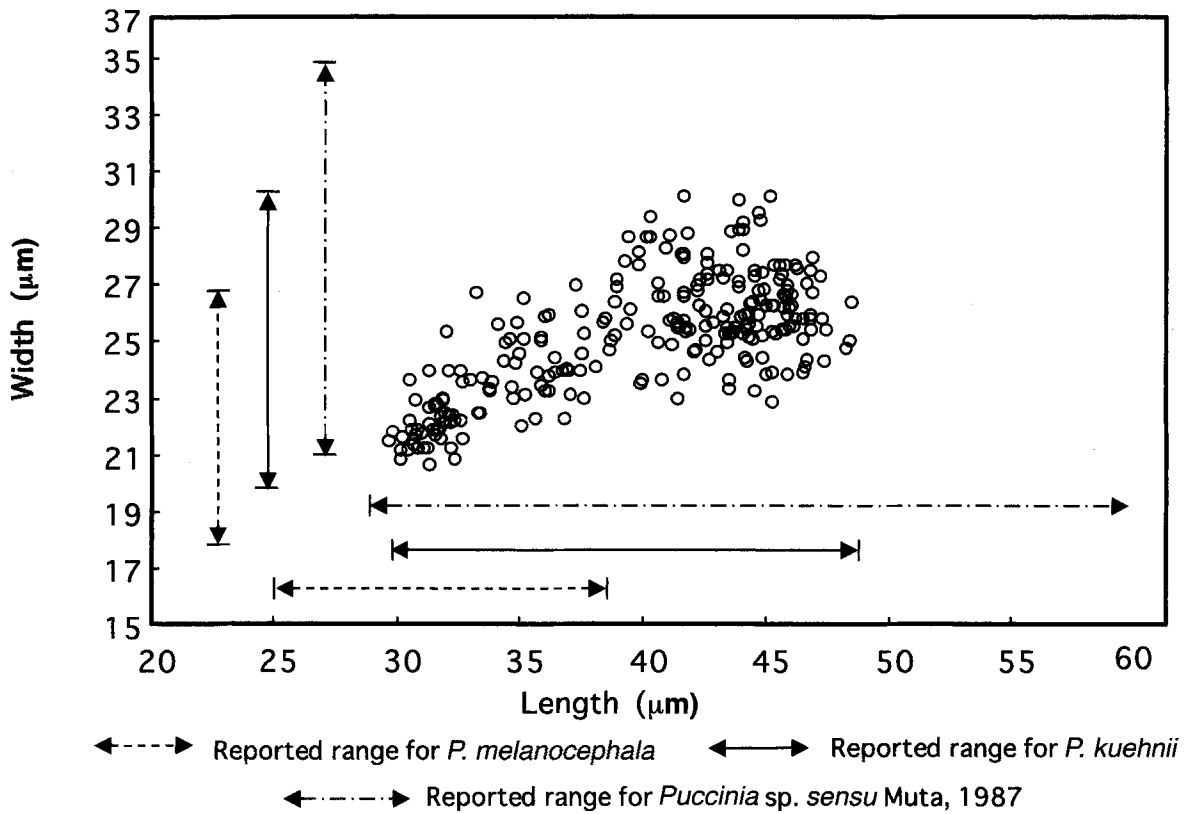


Fig. 3. Distribution plot of specimens of sugarcane rusts based on urediniospore size.

to *P. melanocephala* specimens. Telia in this type were blackish brown and occurred together with uredinia (Fig. 1F). The teliospores were brown to dark brown, mostly clavate, with apically thickened walls, and usually their upper cells were darker than the lower cells (Fig. 1E). Capitulate and colorless to golden brown paraphyses were observed among teliospores of this type.

The second type of telia was found in a few herbarium specimens of *P. kuehnii* and some specimens collected in Japan and the Philippines (Fig. 2G). The telia of this type were whitish and fuzzy due to metabasidia formed *in situ*. The teliospores were hyaline, obclavate, with slight or no constriction at the septum, and walls uniformly thin (Fig. 2F). Three-celled teliospores were sometimes observed. Basidiospores were found in the metabasidial layer above the teliospores. These teliospores were also observed in the specimens used by Hennen (1986) to describe teliospores of *P. kuehnii* (PUR-89541 and PUR-89542). Except for these specimens, teliospores of this type were found in only one other herbarium specimen of *P. kuehnii* collected on *S. officinarum* L. in the Philippines in 1918 (BPI-79621).

Telia and teliospores of this type were also found in some specimens collected from Amamioshima Is. and the Okinawa Islands, Japan and the Philippines, whose uredinal stages were morphologically similar to those of herbarium specimens of *P. kuehnii*. These telial characteristics were also similar to those of *Puccinia* sp. *sensu* Muta (1987) reported in the Nansei Islands, Kagoshima Pref., Japan. Their teliospores are smaller than those of the first type (Fig. 2F).

Discussion

Comparative morphological examinations of uredinal and telial stage characteristics showed that the specimens could be classified into two morphologically distinct groups. The specimens examined could not be clearly distinguished based on color of lesions and uredinia, and the size of urediniospores. However, they were distinguishable based on the presence or absence of abundant capitulate paraphyses in uredinia, echinulation, color and wall thickness of urediniospores, color of the telia and color and wall thickness of teliospores. One group of specimens, including most herbarium specimens of *P. melanocephala*, had abundant capitulate paraphyses in uredinia and urediniospores with dense echinulation, darker brown and uniformly thick walls. They also had dark brown to blackish telia with brown to dark brown teliospores with apically thickened walls. The other group of specimens, including most herbarium specimens of *P. kuehnii* had morphologically indistinct paraphyses in uredinia and urediniospores with moderate echinulation, lighter brown and sometimes apically or uniformly thickened walls. They also had whitish telia and hyaline thin-walled teliospores exhibiting *in situ* germination. Specimens collected in Japan and the Philippines could also be separated into these two groups.

The presence or absence of conspicuous paraphyses in uredinia and telia was found to be an important

characteristic for distinction of the two groups. In previous reports, paraphyses of *P. kuehnii* are variously and sometimes ambiguously described by different authors. Butler (1914) mentioned the occurrence of paraphyses which were described as "club-shaped or cylindrical and brownish found at the margin of the sori." On the other hand, Cummins (1953), Laundon and Waterson (1964), Sivanesan and Waller (1986), and Ryan and Egan (1989) mentioned "inconspicuous, peripheral, cylindrical or obovoid to capitulate, hyaline or pale brownish." However, Ito (1909) and Hennen (1986) did not describe paraphyses in *P. kuehnii*. In this study, paraphysis-like structures observed in herbarium specimens of *P. kuehnii* and specimens collected in Japan and the Philippines were inconspicuous and of various irregular shapes and sizes. Furthermore, their occurrence was not consistent within a specimen. Therefore, we considered that paraphyses are unstable characteristics of this group. As such, we concluded that *Puccinia* sp. reported by Muta (1987) as a species producing no paraphyses is included in this group.

These two groups could also be clearly distinguished based on urediniospore surface characteristics. The first group had dense echinulations, while the second group had bigger, more widely spaced and evenly distributed spines. These results more or less coincide with previous reports of urediniospore surface differences between *P. melanocephala* and *P. kuehnii*. Mordue (1985) reported that *P. melanocephala* and *P. kuehnii* could be differentiated based on spine density and distribution, spines in the former being denser and more regularly spaced except near the pores, where they tend to cluster together. Hiratsuka and Kaneko (1983) reported that *P. melanocephala* spines at base of the spores are bigger and more developed than spines in the other parts of the spore. We also observed these spines in the first group of specimens.

Apical thickening of urediniospore walls was characteristic of the morphology in the second group of specimens. Urediniospores with uniformly thick walls and urediniospores with conspicuous apical thickening were often found together in the same specimen. However, urediniospores with apical thickening were not observed in specimens of the first group.

Telial characteristics also clearly support the separation of sugarcane rusts into the two groups. Previously reported characteristics of *P. melanocephala* coincide with those of the first group. On the other hand, telial stage characteristics of *P. kuehnii* reported by Hennen (1986) and of *Puccinia* sp. reported by Muta (1987) were found to be similar to those of specimens of the second group. It is believed that the teliospores observed by Butler (1914) were indeed immature, as he reported and as suggested by Hennen (1986). This accounts for their smaller size compared to those observed in this study and those reported by Hennen (1986) and Muta (1987). Furthermore, Butler (1914), who described teliospores from *S. spontaneum*, not from sugarcane, apparently did not observe germination of teliospores. His description of the telia as "blackish" is inconsistent with his description

of the teliospores as hyaline or pale yellow, and it is probable that he mistook black hyperparasitic infections as mature telia.

Separation of the sugarcane rusts into these two groups by morphological characteristics corroborates the results of molecular phylogenetic analysis of the D1/D2 regions of the LSU rDNA (Virtudazo et al., 2001). However, the analysis of ITS regions showed that specimens of one group could be further separated into two groups. Although morphological variation was observed among these specimens, it did not correlate with the divergence observed in the ITS regions. Hence, variation in the ITS regions, though considerable, is believed to reflect intraspecific polymorphism rather than inter-species variation.

Taxonomy

Results of comparative morphology showed that sugarcane rust specimens could be clearly distinguished into two morphologically and phylogenetically distinct groups. The characteristics of the uredinial and telial stages of these two groups correspond to previously reported taxonomic characteristics of *P. melanocephala* and *P. kuehnii*. Therefore, sugarcane rust fungi are classified into two species: *Puccinia melanocephala* and *P. kuehnii*.

Puccinia kuehnii Butler, Ann. Mycol. 12: 82, 1914.

Synonyms: *Uromyces kuehnii* Krueger, Ber. Versuchs Stat. f Zuckerrohr West-Java, Kogot-Tegal 1: 120, 1890.

Uredo kuehnii (Krueger) Wakker et Went, De Ziekten van het suikerviet Java, Lieden, p. 144, 1898.

(*Puccinia* sp. sensu Muta, Proc. Assoc. Pl.)
Prot. Kyushu 33: 36, 1987.

Spermogonia and aecia unknown. Uredinia mainly hypophyllous, sometimes amphigenous, linear up to 3–4 mm, yellow-orange to reddish brown, develop subepidermally, erumpent; paraphyses inconspicuous, not always observed, if present basal and/or peripheral, irregular in shape, usually pyriform to clavate, extremely thin walled ($> 1 \mu\text{m}$) and delicate, hyaline to pale brown. Urediniospores mostly obovoid or pyriform, sometimes broadly ellipsoidal, size highly variable, (26.4–) 33.3–52.2 (–67.7) \times (16.0–) 21.3–30.5 (–39.2) μm , walls orange- to cinnamon-brown, 1–2.3 μm thick at the sides, sometimes uniformly thick but usually with pronounced apical wall thickenings up to 10 μm or more, with 4 or 5 equatorial germ pores. The wall moderately echinulate with evenly distributed spines. Telia hypophyllous, erumpent, arising from uredinia, translucent at first, turning whitish upon formation of metabasidia, paraphyses probably present but indistinguishable from immature teliospores. Teliospores sometimes sessile, or with hyaline pedicel, mostly ca. 12 μm long, sometimes more than one spore borne in one pedicel; fusiform to clavate, two- rarely three-celled, with slight or no constriction at the septa, (25.8–) 31.4–54.8 (–65.9) \times (8.3–) 10.7–16.6 (–19.4) μm . The wall hyaline, smooth, and uniformly thin (0.5–1.2

μm). Teliospores germinate without dormancy, germ pores undifferentiated, but germination apical in both cells, basidiospores 7–10 \times 5–7 μm .

Holotype: on *Saccharum spontaneum* L., E. J. Butler, Bassein, Myanmar (HCIO). (not seen)

Specimens examined: On *S. officinarum* L.: Malaysia (PDD-60536); Philippines–Luzon Is. (BPI-79608, BPI-0079615, BPI-79617–22), Negros Is. (BP I-79616, 79623, 79625–7, 79629; TSH-R11201–16, 11229–35), Mindanao Is. (TSH-R11236–7, 11239–50, 11252–5, 11258–61); Indonesia–Java Is. (BPI-79614); Taiwan (BPI-79610–1, 79630, 79634; PUR-89541–2); Hawaii (BPI-79624); Australia (BPI-79612); Micronesia (PDD-50993); Western Samoa (PDD-34296, 34297, 36600, 36403–5, 34298, 34173, 34031); Vanuatu (PDD-43982, 49233, 46817); Cook Islands (PDD-39571, 32989); Fiji (PDD-36402); French Polynesia (PDD-44462); Japan–Amamioshima Is. (TSH-R11001–2, 11004, 11010–3, 11015, 11024, 11026–9, 11032, 11034, 11301–4, 11306–8, 11335–7), Okinawa Is. (TSH-R11061–5, 11067, 11070, 11072–9, 11081, 11085, 11087–9, 11092, 11095, 11097, 11099, 11102–3, 113414), Iriomote Is. (TSH-R11105–6, 11110), Ishigaki Is. (TSH-R11113–4, 11121–2, 11125–6, 11131, 11133–4, 11323–5, 11327), Miyako Is. (TSH-R11137–9, 11144, 11146–7, 11149, 11152–3, 11157–8), Tanegashima, Is. (TSH-R11309, 11311–3, 11315–6, 11318–9, 11321, 11322). On *S. arundinaceum* Retz.: India (PDD-14040, 9362; HCIO-75, 573, 1592; BPI-79606, PUR-F15855, F11422; L-955052-317; S-01, 573, 1592; Japan–Okinawa Is. (BPI-79607). On *S. spontaneum*: Indonesia–Java Is. (BPI-79613); India (BPI-79635, S-2146, KRAM-2146); Hongkong (PDD-57590); Solomon Islands (PDD-38201). On *S. edule*: Fiji (PDD-34271, 36401, 36599, 36406–7); Solomon Islands (PDD-38367, 42120); Vanuatu (PDD-45002). On *Saccharum* sp.: China (BPI-79605, 199088), Taiwan (PUR). On *Sclerostachya fusca* (Roxb.) A. Camus: India (PUR-F8803).

Hosts and distribution: On *S. officinarum* L., Japan (Ito, 1909; Muta, 1987), Australia (Cobb, 1893, cited by Butler, 1914), Indonesia (Krueger, 1890, cited by Butler, 1914), Philippines (Lee, 1922; Ocfemia, 1939), Taiwan (Hsieh et al., 1977); Pacific Islands, Sri Lanka, Malaysia, Thailand, New Caledonia, China (Egan, 1980; Sivanesan and Waller, 1986), India (Mukerji and Bhasin, 1986); On *S. spontaneum* L., India (Sydow et al., 1906a), Burma (Butler, 1914); On *S. arundinaceum*, India (Sydow et al., 1906a; Butler, 1918); On *S. robustum* Brandes and Jesw. ex Grassl, *S. edule* Hassk., New Guinea (Koike et al., 1979); On *S. narenga* Wall., (Laundon and Waterson, 1964; Sivanesan and Waller, 1986; Mukerji and Bhasin, 1986); On *S. barberi* Jesweit and *S. sinense* Roxb. (Ryan and Egan, 1989). On *Sclerostachya fusca* (Roxb.) A. Camus (= *Saccharum fuscum* Roxb.), India (Sydow et al., 1906a; Butler, 1918, Laundon and Waterson, 1964, Mukerji and Bhasin, 1986).

Puccinia melanocephala Sydow et P. Sydow, in (H.) Sydow, (P.) Sydow et Butler, Ann. Mycol. 5: 500,

1906.

Synonyms: *Puccinia eulaliae* Barclay, J. Asiatic Soc. Bengal 60: 216, 1891, *nomen dubium*.

Puccinia erianthi Padwick et Khan, Imp. Mycol. Inst. Kew, Mycol. Papers 10: 32–33, 1944.

Puccinia sacchari Patel, Kamat et Padhye, Curr. Sci. 19: 122, 1950, *nomen nudum*.

Spermogonia and aecia unknown. Uredinia mainly hypophyllous, sometimes amphigenous, linear up to 4 mm, cinnamon-brown to dark brown to blackish in some varieties, develop subepidermally, erumpent; paraphyses abundant, capitate or spatulate, colorless to golden brown, 32–98 μm long, with the head 12–25 μm in diam, the wall 1.0–2.8 μm thick in the stipe and 4–15 μm in the head. Urediniospores obovoid or ellipsoidal, cinnamon-brown to dark brown, (20.6–)25.8–38.7(–44.3) \times (14.8–)17.8–27.5(–32.1) μm . The wall uniformly thick (0.8–2.3 μm), with usually 4, sometimes 5 equatorial germ pores, finely echinulate with regularly spaced spines, sometimes clustered at the pores and more developed at the spore base. Telia hypophyllous, black, erumpent, arising from uredinia, long capitate paraphyses present. Teliospores mostly clavate, two-celled with slight constriction at the septum, (31.3–)34.5–55.2(–61.0) \times (14.8–)16.4–23.2(–25.0) μm . The wall smooth, 2–3.5 μm thick at sides, 2.5–8 μm apically, upper cells chestnut brown to dark brown with lower cells paler, the pedicels dark brown, 4.7–16.5 μm long.

Holotype: on *Erianthus* sp. (probably *E. ravennae* (L.) P. Beauv.) (originally identified as *Arundinaria* sp.), 5 May 1905, E. J. Butler, Nahjan, Khasi Hills, India (S).

Specimens examined: On *S. officinarum* L.: Jamaica-(BPI-33035, 188671, 188688); Dominican Republic-(BPI-188669, 188670); Mexico-(BPI-188643~51, 188653~6, 188658~62, 188664~5, 193824; DAOM-181745; L-983071-886); Costa Rica-(BPI-37734); Puerto Rico-(BPI-188685~6, 188688); Nicaragua-(BPI-188666~7); USA-Texas (BPI-188642, 188652, 188661, 188663, 188690~2, 188694; PUR-F11084); Ecuador-(BPI-189697); Australia-(BPI-113635~6, 113641); Japan-Amamiyoshima Is. (TSH-R11411~4, TSH-R11416~8); Philippines-Negros Is. (TSH-R11401, 11403, 11419). On *E. rufipilis* (Steud.) Griseb: India-(PUR-F14544, USNH-1607370), China-(PUR-F11750, 11753; ENH-1505263, 1722949). On *E. fulvus* Nees ex Stend: India-(PUR-F17947, F16074-type for *P. erianthi*). On *E. ravennae* (L.) Beauv. (originally identified as *Arundinaria* sp.): India-E. J. Butler No. 512 (S-holotype, designated by G. B. Cummins).

Hosts and distribution: On *S. officinarum* L., India (Patel, et al., 1950; Mukerji and Bhasin, 1986), Japan (Ohtsu, 1975 (cited by Muta, 1987)), Philippines (Serra et al., 1983), Australia (Egan and Ryan, 1979), Taiwan (Hsieh et al., 1977), Dominican Republic (Presley et al., 1978), Jamaica (Burgess, 1979; Koike et al., 1979), Puerto Rico (Liu, 1979), Cuba (Sandoval et al., 1983), Caribbean and Central America (Purdy et al., 1983),

Hawaii (Comstock et al., 1982), Angola, Kenya, Malagasy R., Tanzania, Uganda, Zambia, Zimbabwe, South Africa, Mozambique, Malawi (Egan, 1980; Sivanesan and Waller, 1986); On *S. barberi* Jesweit and *S. sinense* Roxb., India (Srinivasan, 1966); On *S. spontaneum* L., India (Singh and Tiwari, 1964); On *S. robustum* Brandes and Jesw. ex Grassl., Puerto Rico (Chu et al., 1982). On *E. ravennae* (L.) P. Beauv., India (Sydow et al., 1906b; Sathe, 1971; Cummins, 1971); On *E. rufipilis* (Steud.) Griseb. (= *E. fulvus* Nees ex Stend.), India (Padwick and Khan, 1944; Cummins, 1953), China (Cummins, 1953).

Acknowledgements—Gratitude is expressed to Dr. Y. Takaesu and Mr. M. Ishimine, Miyako Branch, Mr. T. Oshima, Ishigaki Branch, Dr. K. Uehara, Mr. T. Kinjo and Ms. K. Takaesu, Naha Branch, Okinawa Agricultural Experiment Station, Mr. R. C. Villamayor, and Mr. J. A. Arro, VicMiCo, Negros Occ., Philippines, for assistance during the field collections, and to the herbarium curators for the loan of specimens.

Literature cited

- Burgess, R. A. 1979. An outbreak of sugarcane rust in Jamaica. *Sugarcane Pathol. Newsl.* 22: 4–5.
- Butler, E. J. 1914. Notes on some rusts in India. *Ann. Mycol.* 12: 76–82.
- Butler, E. J. 1918. *Fungi and disease in plants*. Thacker, Spink, and Co., Calcutta and Simla.
- Chona, B. L. and Munjal, R. L. 1950. *Puccinia kuehnii* (Krueg.) Butler on sugarcane in India. *Curr. Sci.* 5: 151–152.
- Chu, T. L., Serapion, J. L. and Rodriguez, J. L. 1982. Varietal reaction and inheritance trends of susceptibility of sugarcane to rust (*Puccinia melanocephala* Syd. & H. Syd.) J. Agric. Univ. P. R. 66: 99–108.
- Comstock, J. C., Tew, T. L. and Ferreira, S. A. 1982. Sugarcane rust in Hawaii. *Plant Dis.* 66: 1193–1194.
- Cummins, G. B. 1953. The species of *Puccinia* parasitic on Andropogoneae. *Uredineana*, *Encyc. Mycol.* 24: 1–89.
- Cummins, G. B. 1971. *The rust fungi of cereals, grasses and bamboos*. Springer-Verlag, New York.
- Cummins, G. B. and Hiratsuka, Y. 1983. *Illustrated genera of rust fungi*. Revised ed. Amer. Phytopath. Soc., Minnesota.
- Egan, B. T. 1980. A review of the world distribution of *Puccinia* spp. attacking sugarcane. *Proc. Intl. Sugarcane Tech.* 17: 1373–1381.
- Egan, B. T. and Ryan, C. C. 1979. Sugarcane rust, caused by *Puccinia melanocephala*, found in Australia. *Plant Dis. Rep.* 63: 822–823.
- Hennen, J. F. 1986. Teliospores of the sugar cane rust *Puccinia kuehnii* Butler on *Saccharum officinarum* L. in Taiwan. *Acta Mycol. Sinica Suppl.* 1: 149–152.
- Hiratsuka, N. and Kaneko, S. 1983. A provisional list of *Puccinia* species on the grasses in Japan. *Rept. Tottori Mycol. Inst.* 21: 61–75.
- Hiratsuka, T. 1958. The species of rust fungi parasitic on the grasses collected in the Southern Kyushu and the Ryukyu Islands, Japan. *Sci. Bull. Agric. Home Econ. & Engg. Div. Univ. Ryukyus* No. 5.
- Hsieh, W. H., Lee, C. S. and Chan, S. L. 1977. Rust disease of sugarcane in Taiwan. *Taiwan Sugar Res. Inst. Ann. Rep.*, pp. 38–39.
- Ito, S. 1909. On the Uredineae parasitic on the Japanese Gramineae. *J. Sapporo Agric. Coll. Japan III.*, pp. 244–245.

- Koike, H., Flora, G., Pollack, G., Lacy, S. and Dean, J. L. 1979. Rust of sugarcane in the Caribbean. *Plant Dis. Rep.* **63**: 253-255.
- Laundon, G. F. and Waterston, J. M. 1964. *Puccinia kuehnii*. CMI Descriptions of Fungi and Bacteria No. 10.
- Lee, H. A. 1922. Observations on previously unreported or noteworthy diseases in the Philippines. *Phil. Agric. Rev.* **14**: 422-434.
- Liu, L.-J. 1979. Rust of sugarcane in Puerto Rico. *Plant Dis. Rep.* **63**: 256-258.
- Mordue, J. E. M. 1985. Urediniospore ornamentation in the sugarcane pathogens *Puccinia kuehnii* and *P. melanocephala*. *Trans. Br. Mycol. Soc.* **84**: 758-760.
- Mukerji, K. G. and Bhasin, J. 1986. *Plant Diseases of India: A Source Book*, pp. 218-219. Tata McGraw-Hill Publishing Company Ltd. New Delhi.
- Muta, T. 1987. Occurrence of sugarcane rust (*Puccinia melanocephala* and *Puccinia* sp.) in Kagoshima Prefecture. *Proc. Assoc. Pl. Prot. Kyushu* **33**: 36-38.
- Ocfemia, G. O. 1939. A review of sugarcane diseases in the Philippines. *Proc. 6th Cong. I.S.S.C.T.*, Baton Rouge, pp. 183-189.
- Padwick, G. W. and Khan, A. 1944. Notes on Indian Fungi II. *Mycol. Pap.* **10**: 10-11.
- Patel, M. K., Kamat, M. N. and Padhye, Y. A. 1950. A new record of *Puccinia* on sugarcane in Bombay. *Curr. Sci.* **19**: 121-122.
- Presley, J. T., Perdomo, R. and Ayats, J. D. 1978. Sugarcane rust found in the Dominican Republic. *Plant Dis. Rep.* **62**: 843.
- Purdy, L. H. 1985. Sugarcane rusts. Chap. VIII. In *The Cereal Rusts*. v. II., (ed. by Roelfs, A. P. and Bushnell, W. R.), pp. 237-256. Academic Press, Inc., Orlando.
- Purdy, L. H., Liu, L. J. and Dean, J. L. 1983. Sugarcane rust, a newly important disease. *Plant Dis.* **67**: 1292-1296.
- Ryan, C. C. and Egan, B. T. 1989. Rust, Chap. XIII. In *Diseases of Sugarcane, Major diseases*. (ed. by Ricand, C., Egan, B. T. Gillaspie, Jr., A. G. and Hughes, C. G.), pp. 189-210. Elsevier, Amsterdam.
- Sandoval, I., Picornell, V., Chavez, R. and Ramos, M. 1983. *Puccinia melanocephala*. H. & P. Syd.: Biological and ecological aspects. *Proc. Int. Soc. Sugar Cane Technol.* **18**: 845-853.
- Sathe, A. V. 1971. Nomenclatural revision of the common rust fungus affecting sugarcane. *Curr. Sci.* **2**: 42-43.
- Serra, R. J. and Barredo, F. C. and Tiangco, A. P. 1983. Incidence of sugarcane rust (*Puccinia melanocephala* H. et. P. Sydow) in the Victorias Milling Company District Occidental Negros, Philippines in 1982. *Philipp. Phytopath.* **19**: 50-53.
- Singh, K. and Tiwari, M. M. 1964. Sugarcane rust-collateral hosts and physiologic specialization. *Indian J. Sugarcane Res. Dev.* **8**: 275-276.
- Sivanesan, A. and Waller, J. M. 1986. Sugarcane diseases. Commonwealth Mycological Institute Phytopath. Paper No. 29.
- Srinivasan, K. V. 1966. Studies of resistance to rust of sugarcane. *Sugarcane Breed. Newsl.* **18**: 80-81.
- Sydow, H., Sydow, P. and Butler, E. J. 1906a. Fungi Indiae orientalis I. *Ann. Mycol.* **4**: 422-445.
- Sydow, H., Sydow, P. and Butler, E. J. 1906b. Fungi Indiae orientalis II. *Ann. Mycol.* **4**: 485-501.
- Tai, F. L. 1947. Uredinales of Western China. *Farlowia* **3**: 95-139.
- Virtudazo, E. V., Nakamura, H. and Kakishima, M. 2001. Phylogenetic analysis of sugarcane rusts based on sequences of ITS, 5.8S rDNA and D1/D2 region of LSU rDNA. *J. Gen. Plt. Path.* **67**: 28-36.