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PERONOSPORA TABACINA A. THE CAUSING AGENT OF BLUE MOLD DISEASE ON TOBACCO

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Abstract

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Blue mold is a disease of plants that is caused by *Peronospora tabacina* Adam (Family: Peronosporaceae) and can cause severe damage on tobacco crop. Due to the economical importance of PtA, a collaborative study of blue mold has been made in several countries through the world provided by CORESTA and AERET. Here, we present data on ten years monitoring (2003-2012) of the pathogenic effect and intensity of attack of the fungus (PtA) on different tobacco varieties from various countries and climate conditions and to estimate the degree of resistance tobacco varieties to the pathogenic fungus PtA. Also we investigated morphology and ecology of the pathogen PtA.

Field trials with tobacco varieties were set up in randomized block with four replications at the experimental filed of Scientific Tobacco Institute - Prilep for realization of those investigations. Different tobacco varieties in Macedonia expressed various reactions to PtA. Up to now the overall analysis indicates that Chemical Mutant and Bel 61-10 are the most resistant varieties, followed by the flue cured variety V53 from Macedonia.

In future, although the climatic changes are causing very dry periods, we must take concrete measures, integrated pest management program (fungicides, resistant cultivars) for escaping serious damage that can be caused on oriental tobacco plants grown in Macedonia.

Key words: tobacco varieties, blue mold, *Peronospora tabacina* A.

Introduction

Many plant diseases are spread from their area of origin into countries where they have not existed before. These events often have had disastrous consequences for man (Klinkowski, 1970). Different tobacco varieties in different countries expressed various reaction to PtA. Blue mold is, historically, the major disease on tobacco crop. The first findings of PtA come from northern Australia from 1881 when the disease was determined on cultural and wild species of tobacco. This continent is considered the homeland of PTA (Dimeska et al., 2007). Over time the disease has spread to almost all countries in the world that produce tobacco. The disease was first reported in the U.S. in 1921 in Florida and Georgia, and reappeared in the same region in 1931, spreading north into North Carolina, Virginia and Maryland; in subsequent years, it spread farther into the burley tobacco producing areas of Kentucky and Tennessee. In North Carolina, blue mold is introduced each year by windblown spores or from the importation of infected transplants from outside the region because the pathogen does not typically over winter in this state (Ivors and Mila, 2007).

PtA is also very alarming towards humid farming zones, like the southeastern and eastern U.S., Canada, and countries boarding the Caribbean. In Europe, the blue mold was reported for the first time on tobacco crops in July 1959. It has been registered in several countries in Europe, first in the Netherlands and Belgium then it spread to Germany, France, Italy, and Romania etc. In 1960 a blue mold epidemic spread on tobacco in approximately eleven countries. There were huge losses which were nearly thirty percent of tobacco plants. The blue mold has reached Mediterranean countries in 1960. In Macedonia, during the 1961 disease occurs on seedlings in tobacco production area in Prilep, Bitola and Radovish. In 1963 the disease could

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be considered endemic in most countries of Europe, North Africa and the Middle East (Corbaz, 1964). Nowadays, blue mold is serious threat that can cause severe damage to susceptible tobacco plants in many parts of the world.

Under favorable weather conditions, the disease spreads rapidly. Cloudy and wet weather conditions contribute to rapid development to this severe blue mold, while sunny and dry weather stops its development. Conidiophores produce small reproductive units called conidia. These are of primary importance for the spread and development of blue mold on tobacco. Downy mold carries thousands of conidia. When the blue mold occurs, if tobacco plants are not chemically treated, the cycle may quickly be repeated several times during the growing season. This can cause a huge epidemic, causing infection of many plants. The disease was controlled by application of fungicides, but sometimes spontaneous disease development was stopped by weather conditions (dry climate).

Peronospora tabacina is highly destructive to tobacco seed beds, transplants and production field especially in the humid farming zones. Tobacco (*Nicotiana tobaccum*) is primary host for this disease. Other hosts include pepper plants (*Capsicum annum*), tomato (*Solanum lycopersicum*) and eggplants (*Solanum melongena*) and they can also be reservoirs of disease. Due to the economic importance of tobacco for Macedonia, this research is contribution on emergency measures to combat the cause of blue mold.

Materials and Methods

The PtA and the pathogenic effect of the fungus on tobacco were investigated for ten years (2003-2012). Due to the economical importance of PtA as causing agent of blue mold disease on tobacco, a collaborative study of blue mold has been made in several countries through the world provided by CORESTA (Cooperation Centre for Scientific Research Relative to Tobacco) each year. In 2005, CORESTA and A.E.R.E.T. (European Association for Tobacco Research and Experimentation) decided, that the former Blue Mold Early Warning Service, provided by CORESTA, will be taken over by A.E.R.E.T. The purpose of the service remains the same: „The purpose of this service is to collect and compile information on the spread of blue mould in the Euro-Mediterranean zone during the growing season, and to disseminate it to collaborators throughout the Region (CORESTA website)." From the project coordinator we obtained protocol of the experiment and seed samples of the complete list of introduced tobacco varieties in the experiment through the years.

Local varieties included in the experiment were created in Scientific Tobacco institute Prilep. Growing stages of the varieties were investigated both in seedbeds and after transplanting. Traditional cultural practices for this region were applied during growing period (use of herbicide, fertilization, irrigation, regulation of temperature regime, preventive protection with insecticide and etc.) Sowing usually starts at March; transplantation is during May and early June.

Field trials with tobacco varieties were set up in randomized block with four replications at the experimental filed of Scientific Tobacco Institute - Prilep for realization of those investigations. Varieties of Collaborative Experiment were placed near large-leaf tobaccos on colluvial/alluvial soil. (Plants/ha: 45 454, Plot size (m^2): 63 m^2, Total plants/plot - 22, Evaluated plants plot - 22, Spacing between rows: 45 cm. Spacing within rows: 50 cm). Experimental design was - 2 rows for each variety; 11 plants for the row (22 plants for each variety); all varieties in 4 replications (88 plants for variety). Fertilization: in seed beds with KAN (saltpeter) 5-10 g /m^2; if necessary, in field with 300 kg NPK (8:22:20)/ha.

Irrigations were adapted on the climatic conditions (high temperatures, drought). Plant protection is made once in seedbed with adequate herbicide and insecticide, and if conditions were favorable for disease occurrence, preventive protection is made with contact fungicide. In field protection is made only with adequate insecticide.

Disease growth was monitored and more profound investigation of the PtA was made. Many observations were made continuously during the tobacco vegetation and through the all investigated years. Also every year were monitored the Meteorological data of the Prilep region (~ mean daily temperature, ~ mean daily humidity, ~ daily rainfall).

The intensity of PTA attack is estimated according to CORESTA recommendation scale (Table 1). At some loca-

Table 1
Scale for assessment of the degree of infestation with PTA

Scale 1 - 9	0 - 9 (10, 11) scale	% leaf area damaged *
1	0	0 – 0.6 %
2	1	0.6 - 3 %
2	2	3 - 6 %
3	3	6 - 12 %
4	4	12 - 25 %
5	5	25 - 50 %
6	6	50 - 75 %
7	7	75 - 87 %
8	8	87 - 93 %
9	9	93 - 97 %
9	10	97 - 100 %
9	11	100%

* All blue mold symptoms (sporulation, systemic)

tions, the infestation of single plants was separated in three parts: bottom, middle and top. At all locations the infestation was rated by numbers using either a scale from 0 (no blue mold) to 9 (10, 11) (very serious attack) or 1 (no blue mold) to 9. For the overall analyses, the different rating schemes were "translated" to a 1 to 9 scale and overall means over single plant and/or single plant parts were calculated.

According the Blue mold collaborative group and info service to describe the varieties regarding their behavior to blue mold attacks, two parameters were calculated: the mean rating values and the slope of the regression lines of the scores over the rating dates! The latter gives an indication how fast blue mold evolves on a given variety - the higher the value the faster the evolvement!

The varieties were classified into three classes: resistant (rating < 3.0 and slope < 0.1), tolerant (rating between > = 3.0 and < 5.0 and the slope between > = 0.1 and < 0.175) and susceptible (rating > = 5.0 and slope > = 0.175). Each year the project participants from each country send the results to the project coordinator, at the end of the growing season. Then the project coordinator collates the results and makes report average results for PTA resistance for each variety.

Results

Disease is easy to identify based on symptomology and presence of characteristic downy gray-blue mold on the lower side of infected leaves. To better cope with the disease, knowledge of the life cycle of the blue mold is important. After inoculation, the fungal development starts.

If Conidia germinate reaches the healthy tobacco leaves, infestation leads to vegetative growth of the fungus (Figure 1) within the leaf surfaces (appressorial formation, penetration and vesicle formation, first growth beyond vesicle, growth to bottom of epidermal cell, entrance to intercellular space or palisade cell). Haustoria are most concentrated in the spongy parenchyma and lower epidermis of susceptible leaves.

When the ambient air becomes humid, conidiophores grow through stomatal openings, branch dichotomously, and rapidly produced conidio-spores. The ability of this pathogen to produce a great number of conidia per square centimeter of leaf enables its rapid reproduction in ideal weather conditions.

The asexual life cycle is associated with a short incubation period. The asexual cycle is completed for 5-7 days by emergence of new conidiophores and their production of conidia (Figure 2). Under favorable conditions, a second set of spores is usually produced 7-10 days after initial infection. Released conidia are dispersed by air currents to neighboring plants and crops. This cycle may be repeated several times under favorable conditions and without chemical control, and can cause many generations of conidia during the tobacco growing season.

Incubation becomes longer with less than ideal conditions and with the age of the tobacco plants. Under unfavorable environmental conditions in the life cycle of this pathogen, sexual phase may be occurred (formation of oospore in the leaf tissue of infested tobacco). Disease occurs both on seedlings and planted tobacco.

The symptoms of PtA usually take place before it obvious. The incubation period lasts for 5 to 7 days, and the upper

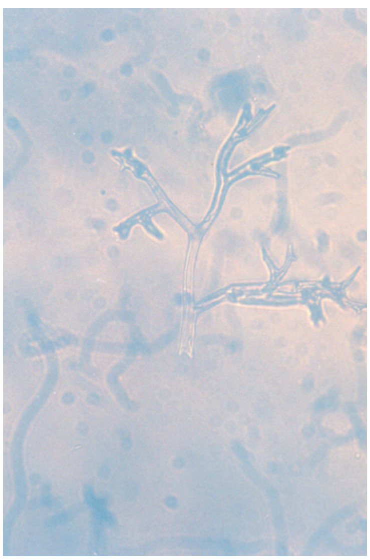

Fig. 1. Mycelia - PtA

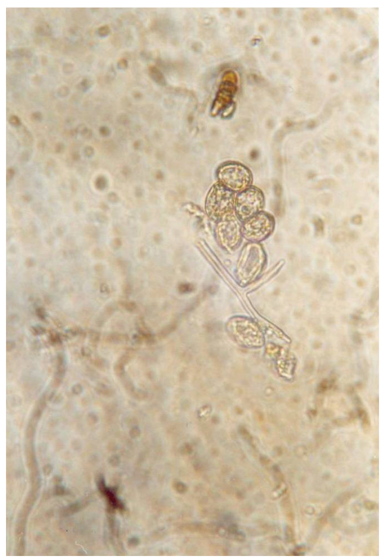

Fig. 2. Conidia - PtA

surface of infected leaves will remain almost normal in their appearance. The typically early signs of blue mold in small patches of seed beds first appear as single circular, yellow areas of diseased small seedlings (seedlings with leaves 2-4 cm in diameter). In its early stages, blue mold can easily be confused with cold injury, malnutrition, or damping-off.

Symptoms of Blue mold disease in transplanted tobacco are recognized by the appearance of yellow spots on the leaf. The symptoms are localized in the beginning, but later their number increases, and occupies most of the leaf area, including leaf veins (Figures 3, 4 and 5). In 2003-2005 the varieties Bergerac C, Samsun and Ps 108 were estimated as highly susceptible. Resistance to PtA was noticed in varieties Bel 61-10, Ch. Mutant and Nc 11-51 (Tables 2, 3 and 4).

Fig. 3. ***P. tabacina***

In 2006 and 2007 as a result of extremely dry weather and high temperatures, no symptoms of blue mold attack were recorded on tobacco fields in Macedonia. In Macedonia in period 2006 to 2008 resistance to PtA was noticed in varieties Bel 61-10, Ch. Mutant and V53. The most susceptible variety in 2009-2011 investigation periods was Jupiter. Chemical Mutant, Bel 61-10 is the most resistant varieties, followed by the flue cured variety V53 from Macedonia (Table 5)

During the 2012 in Macedonia, no symptoms of PtA were noticed in the varieties subject of our study, i.e. all varieties remained healthy. Some varieties are susceptible to blue mold, but some appear more tolerant than others or they have good resistance to blue mold.

We must make the environment less favorable for the pathogen to survive and infect tobacco, so we must use cultural and sanitation practices because they can prevent the establishment of blue mold or slow its spread.

Discussions

Blue mold is one of the economically important diseases that exist and cause serious damages to tobacco crops. The disease is caused by pathogenic organism *Peronospora tabacina* Adam (1933). *P. tabacina* belongs to the Genus Peronospora, Family Peronosporaceae in the Order Peronosporales, Class Oomycetes of fungi. The Synonyms are: *Peronospora hyoscyami* f. sp. *tabacina* Skalický (1964), *Peronospora effusa* var. *hyoscyami* Rabenh, *Peronospora hyoscyami* de Bary (1863), *Peronospora hyoscyami sensu* Thümen (1863), *Peronospora nicotianae* Speg. (1891) (Sukno et al., 2002).

Fig. 4. Samsoun tobacco attacked by PtA

Fig. 5. Bergerac C tobacco attacked by PtA

P. tabacina is a pathogen of solanaceous plants, particularly *Nicotiana tobaccum* and some other Nicotiana spp. (*N. glauca, N. rustica, N. glutinosa, N. tomentosa, N. longiflora*). It is an obligate parasite that requires a living host in order to grow (must have living tobacco tissue).

Once blue mold is present, its development depends on weather conditions. Spores require wet leaves for germination and infection. Under favorable weather conditions the symptoms evolve rapidly and typically are noticeable over night. Visible yellow lesions on leaves appear. Some of these leaves are normally spotted with gray, or a bluish downy mold on the lower surface; hence the name blue mold. Then the young plants become twisted and begin to die and turn light brown.

Blue mold can affect plants in the field throughout the growing season. Single or groups of yellow spots appear on the older, shaded leaves. Often the spots grow together to form light brown, necrotic areas. Leaves become distorted,

Table 2
Degree of PtA attack – 2003

Variety	Estimation 2,0 - 30,0					
	C o u n t r y					
	North Italy	R. Macedonia	Iran	Iran	Cuba	USA
Bel 61-10	2	2	2	4.7	10.7	-
Bergerac C	4	12	2.3	17.5	28.6	21.5
Chemical mutant	2	2	2	4.2	9.5	9.8
GA 955	2	2	2	4.5	12.8	11
R x T	2	2	2	7.5	13.2	-
Samsun	2	2	2	10.5	22.8	-
Trumpf	2	2	2	10	14.5	15.8
NC 11 - 51	2,0	2	2	7.7	9.5	12
Habana 92	2	2	2	6.2	10.8	9.5
ITB 261	2	2	2	11.5	14.1	17.8
Ps 108	2	2	2	15	23	-
V 53	2	2	2	6.7	-	8.3
P - 23	-	2.4	-	-	-	-

Table 3
Degree of PtA attack - 2004

Variety	Estimation 2,0 - 30,0						
	C o u n t r y						
	France	North Italy	R. Macedonia	Iran	Iran	Germany	USA
Bel 61-10	3.7	2.2	2	6	2	2.8	4.5
Bergerac C	24.4	2.2	9.3	5.4	18.2	11	21.5
Chemical mutant	2.7	2.8	2	4.5	2	2	5.5
GA 955	5.2	2.2	2	2	2	2	12.5
R x T	8.3	2	2	3	2	7.3	13
Samsun	18.7	2.2	7.2	4.5	2	2.5	18
Trumpf	8.7	2	2	4	4.5	4.3	11
NC 11 - 51	3.2	3.2	2	2	2	2	5.5
Habana 92	5.6	2.7	2	3.5	2	2	10
ITB 261	6.2	3.6	2	5.5	2	10.7	11.5
Ps 108	9.6	3.7	4.6	7	2	3.3	17
V 53	6.6	2.3	2	5	2	5.7	10.4
P - 23	-	-	3.9	-	-	-	-

large portions disintegrate, and the entire leaf may fall apart. Blue mold can destroy leaves at any growth stage. Lesions may occur on buds, flowers, and capsules. In severe situations, blue mold may also cause systemic stem infections (the vein of the leaves reaches vascular tissue of the stem) resulting in partial or overall destroy the plant.

The infection causes abnormal growth and the leaves become narrow and short. The plants usually become deformed, dark, and the weakened stalk usually falls over. Mycelia may persists on leaves, and may over-winter in host tissues, particularly in stalks left in the field after harvesting, thus constituting primary sources of infection. Conidia can be dispersed thousands of kilometers by weather conditions and are primary source for epidemics. Rain showers followed by gusts of wind caused violent leaf movement and the number of conidia increases significantly.

Table 4
Average PtA attack – 2005

C o u n t r y	Estimation 2,0 - 30,0
	Average PtA attack
France	26.6
South Italy	16.4
North Italy	2
Switzerland	2
R. Macedonia	2
Hungary	2
Poland	2
Germany	2
USA	2

Another common spreading way of the blue mold is by distribution of infected plants. The farmers may introduce blue mold into new fields while transplanting infested plants. We must grow own plants, or buy them from a reputable, local source. We do not set any plants from blue mold infested sources, and we destroy all plants with blue mold within the tobacco beds and also we destroy tobacco beds after transplanting because old tobacco bed are usually ideal for the disease and for spreading spores to the crop in the field (Ivors and Mila, 2007).

Intensity of attack controls the disease and determines the quality of tobacco leaves. If there is a systemic outbreak of disease the whole production can fail. During the ten years of our monitoring we observed the disease and its spread in tobacco seedling beds and tobacco field crops in relation to tobacco variety and meteorological conditions.

The environment (relative humidity, diffusion pressure, temperature and light) affects many aspects of the life cycle of this pathogen. Conidial infection depends on temperature and how long the leaf is wet. Suitable conditions are high relative humidity of the air and appearance of dew in the morning. Sporulation was most abundant when increase relative humidity occurs at night or over prolonged periods of overcast weather. The conidia were produced at daybreak each morning if moisture and temperature relationships were favorable. Thus, this relationship with water plays a major role in the formation of conidia.

Table 5
Collaborative experiment on varieties 2009-2011 Report Santiago Coordinator:Norbert Billenkamp SC Liaison: Dongmei Xu

	Rating				Slope			
	Year				Year			
	2009	2010	2011	Mean	2009	2010	2011	Mean
Jupiter	5.66	6.26	6.24	5.68	0.142	0.1411	0.2398	0.1743
Bel61-10	1.72	2.21	1.09	1.04	0.0475	0.0088	0.0141	0.0235
Chemical Mutant		1.68	1.49	1.28		0.0186	0.0211	0.0198
BCE/09/VC1	2.92	3.77	3.33	3.05	0.1067	0.099	0.1205	0.1087
HYV 27 * Germany		3.06	2.29	2.15		0.0671	0.098	0.0826
B911*Germany	2.53	3.1	2.69	2.43	0.0644	0.0673	0.1207	0.0841
ITB_420*France	2.07	2.15		2.11	0.0547	0.0432		0.049
ITB_569*France	2	2.6	2.12	2.24	0.0426	0.0353	0.0725	0.0501
ITB_583*France	2.74	3.14		2.94	0.0581	0.0734		0.0657
Stella*Switzerland	2.44	3.48	2.64	2.85	0.0638	0.1279	0.0707	0.0875
B-2/93*FYROM	3.13	3.35	2.31	2.93	0.0818	0.1023	0.0792	0.0878
V53*FYROM	1.2	2.06	2.44	1.9		0.0247	0.0909	0.0578

We must irrigate tobacco seed beds early in the day to allow drying before nightfall, and then we must manage temperature and ventilation systems to minimize leaf-surface moisture (Ivors and Mila, 2007). Because spores require wet leaves for germination and infection, when weather permits, we must remove plant bed covers to aid drying of the foliage. Rainy years are suitable for emergence and development of the pathogen, so disease occurs with the highest intensity. Therefore in lowland areas and no wind sites where conditions for long-term retention with dew are favorable, the tobacco planting is problematic. We must avoid shady, moist locations with poor drainage and excess nitrogen fertilization (Ivors and Mila, 2007). Optimal environmental conditions for vegetative development of PtA are 15-22˚C, 97-100%, relative humidity and low light.

Weather conditions in Macedonia confine the problems with *P. tabacina*. The oriental tobacco crop escapes serious damage during the vegetation period because of the small amounts of rainfall and high temperature. On the other hand we always take precautionary measures with adequate cultural practices and adequate fungicides. Planting of resistant cultivars are valuable aids. This pathogen has developed resistance to some chemicals. The widespread use of systemic fungicides is the main deterrent of blue mold. We use a regular, preventative fungicide spray program in tobacco seed beds, and we protect tobacco plants with fungicides when they are most vulnerable.

The mechanisms of controlling the blue mold resistance are highly complex. The difficulties in its controlling trigger attempts to locate the sources of resistance. Different tobacco varieties in different countries expressed various reaction to PtA. The general impression is that the attack of blue mold in the experimental blocks was with weak intensity during the 2003-2005. From 2003 to2005 resistance to PtA was noticed in varieties Bel 61-10, Ch. Mutant and V53. From the reports of the emergence and spread of disease in the Euro-Mediterranean zone for 2006 and 2007 it can be seen that the disease first appears in countries with favorable conditions for its development-Iran, Tunisia, France, Italy. Its spread is prevented by weather conditions and the application of appropriate fungicides.

In 2008 most reports came from France and Germany, but blue mold was also present in Italy, Switzerland, Hungary and Iran. Blue Mold was widespread all over Europe but it wasn't a very big problem in any country. In general, in 2009 the infestation with blue mold at nearly all locations was low and the evolvement slowly. Blue mold wasn't a big problem in the European - Mediterranean Zone this year. In 2009 resistance to PtA was noticed in varieties Bel 61-10 and V53. In 2010 in France as well as in Germany the infestation with blue mold was higher compared to 2009. Due to the sensitive strain, the evolvement of blue mold in Germany was much faster. Sporadic out-break on Oriental Tobacco in Macedonia was under control during the 2010. Resistance to PtA was noticed in varieties Chemical Mutant and V53 (Billenkamp, 2010).

According the Collaborative Experiment, in 2011 there is outbreak on bottom leaves on all varieties. Due to the dryer periods the infection stopped and there are sporadic, local spots on middle and upper leaves on some tobacco varieties. As stated by the reports and updates, Spain (Tietar and Alagon valley) and South West France had the most difficulty with the blue mold in 2011. This year as a result of extremely dry weather and high temperatures, no symptoms of blue mold attack were recorded on tobacco fields in Macedonia. Resistance to PtA was noticed in varieties Chemical Mutant and Bel 61-10 (Billenkamp, 2011).

Blue mold was not a serious problem in 2012 in the European – Mediterranean Zone. Only in France, Poland and Germany blue mold occurred, but not in countries of Southern Europe and the Near East. Due to fungicide treatments and dry weather conditions, the development of blue mold was stopped in the fields and area. During the current year in Macedonia, no symptoms of PtA were noticed in the varieties subject of our study, i.e. all varieties remained healthy.

Up to now the overall analysis indicate that Chemical Mutant, Bel 61-10 is the most resistant varieties, followed by the flue cured variety V53 from Macedonia.

Conclusion

The ten-year investigations on the pathogenic effect of PtA in various tobacco producing countries, led to the following conclusions: Different tobacco varieties in Macedonia expressed various reaction to PtA. Up to now the overall analysis indicates, that Chemical Mutant and Bel 61-10 are the most resistant varieties, followed by the flue cured variety V53 from Macedonia. By cultivation of resistant varieties, the application of chemicals will be considerably reduced. When blue mold warnings are issued in our area, we must begin with chemical control.

Thereby, long-term economic effects will be achieved, which will also be a contribution to a healthier environment. In future, besides we expect dry weather, high temperatures and little rain in vegetation season in Macedonia, we must take precaution measures: integrated pest management program (fungicides, resistant cultivars...) and serious damage can be escaped for our oriental tobacco.

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