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Evaluation of Physicochemical Properties, Drying Process and Drying Conditions of Natural Rubber Latex and Ribbed Smoked Sheets

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ABSTRACT: Natural rubber (NR) is an important export commodity in Nigeria with versatile applications in many industries. Its latex or lump forms are regarded as the farm gate while the ribbed smoked sheet (RSS) is the raw materials feeding the rubber industry and both are very essential in the productions process. Consequently the objective of this paper is to investigate the Evaluation of physicochemical properties, drying process and drying conditions of natural rubber (NR) latex and Ribbed Smoked Sheets (RSS) obtained from Benin City, Nigeria using appropriate standard procedures. Data obtained show that the constituents of *Hevea* (NR) latex are dry rubber content (%) 35.60; Lipids (%) 1.08; Protéines (%) 1.23; Carbohydrates (%) 1.40; Minerals (%) 0.47; Water (%) 60.22; Sspecific gravity (28 °C) 0.931± 0.003; Total solid content (TSC) (%) 43.20 ± 1.03; Mechanical stability M.S.T (%) 650 ± 1.06; Volatile fatty acids VFA (%) 0.18 ±0.07; Nitrogen Content (%) 0.55 ± 0.03, while the property of the ribbed smoked sheets (RSS) were Dirt % (wt) 0.15; Ash % (wt) 0.11; Volatile matter % (wt) 0.38; Wallace plasticity Po (47), PRI (74) and lightly brown in colour. The results obtained showed that processing NR into RSS not only served as a preservative, which improved the storage durability, but also imparted flavour, aroma, and attractive colour to the cured sheets. This study sheds more light on the processing, storage conditions, durability, and efficient production of high-value-added RSS developed from natural rubber latex.

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Natural rubber (*Hevea brasiliensis)* is an important economic tree grown primarily for its latex. It is composed exclusively of an unsaturated, linear molecule with long chain aliphatic *cis*-1, 4 polyisoprene hydrocarbon polymer (Dixit and Taniguchi 2023). *Hevea* trees produce high-yield latex within a tapping period of 30-35 years and are source of revenue to rubber farmers. NR is a unique biopolymer of strategic importance that synthetic polymers cannot replace because of its special properties, such as high resilience, elasticity, abrasion resistance, impact resistance, and malleability at cold temperatures (Bhadra *et al*. 2019). It is a versatile material used in a wide range of products, including tires, automotive parts, footwear, medical devices, and various consumer goods. A recent report showed that tires and tire products account for 75% of the world's consumption of natural rubber yearly (Ramli and Yusof 2023).

In Nigeria, *Hevea* is found in Edo, Delta, Cross River, Akwa Ibom, Abia, Imo, Rivers, Ondo, Ogun, and Bayelsa. Recently, natural rubber has been introduced to marginally rubber producing states like Benue, Taraba, Kaduna, Anambra, Enugu, Ebonyi, Osun, and Ekiti States. Nigeria, which is ranked eighth in natural rubber production globally in 1988 (FAOSTAT, 2024), has shifted its emphasis to other

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crops and non-agricultural investments. The natural rubber plantation development stagnated at approximately 200,000 hectares between 1965 and 2000, based on reports from the Rubber Research Institute of Nigeria. A later survey carried out by the Raw Materials Research and Development Council of Nigeria showed that the area planted to rubber dropped to 144,200 ha by 2004 (Okwu, Eguavoen, and Okore 2005). Thus, the decline in the production of natural rubber emanated from the cutting down of rubber trees, which were substituted with food crops such as oil palm, cassava, maize, plantains, etc. Also, the recent growth in population and subsequent urbanization in the country have added its own share in demand for land, which has resulted in changes in land use (Nathaniel and Bekun 2020). More recently, rapid urbanization in Edo, Delta, Cross River, Ogun, and Rivers states has adversely affected natural rubber development efforts in many rubber plantations within the towns close to cities in these rubber-producing states. The changes have led to a decrease in available agricultural land in favour of the provision of residential accommodation in most urban settlements. The consequence reduction in natural rubber hectarage led to a shortage of raw materials for NR processing factories and the closure of some industries(Abolagba *et al*. 2016). There were fifty-seven rubber processing factories with a total installed capacity of 105.5 mt/hr, capable of processing 600,000 mt per year at full capacity in 2014. An estimated 143,000 mt/annum of raw materials were only available for the processing factories, which led to several factories operating at low capacity while other factories were left idle. As of today, 41 rubber processing factories exist in Nigeria, with only 27 of these factories operational (Momodu *et al*. 2017). The Nigerian Government's Economic Recovery and Growth Plan (ERGP), aimed at repositioning the economy on the path of diversification and sustainable and inclusive growth, was recently enacted. This policy has led to a resurgence of activities in the Nigerian rubber industry, with more focus on the production of high-value products with great efficiency and processing techniques. This has given the smallholder farmer the opportunity to store their rubber products for a considerable time and at a reasonable cost. This effort could therefore increase the smallholder farmer’s earnings and will be a major breakthrough in natural rubber cultivation in Nigeria. Revamping natural rubber cultivation in Nigeria through the value addition of farm produce could increase the earnings of smallholder farmers as rubber estates generally market their produce more efficiently due to an improved marketing system that assures a better price. The estate plantation companies are known to have well-established facilities for processing high-quality grades of natural rubber products and a centralized marketing setup, which enables them to make direct sales to consumers. On the other hand, the small holders are known to sell their farm produce, which is usually in the form of latex or coagula, to the intermediate buyers at a very poor discount price. Therefore, processing and marketing of natural rubber by small holders as value-added products can lead to improved pricing for natural rubber farmers, this can sustain their interest in the industry.

Processing of fresh NR latex into ribbed smoked sheets (RSS) is an old method of value addition to field latex, which was the most significant product of the rubber industry before the 1970s in Nigeria. The attention of the industry later turned to creep rubber and technically standard rubber. Previously, rubber latex could be processed into ribbed smoked sheets with a manually operated rubber roller sheeting machine. The machines could not be used for large-scale production as they were manually operated. On the other hand, estate owners with good resources focused on creep rubber and TSR production till date. For the continuous existence of natural rubber as the raw materials market feeding the rubber industry, production of value added product must be shifted from large-scale industries to smallholder farmers at the community-level factories / cooperatives which are mostly located around NR farm settlement near rubber tree plantations. The modernization of invention from a manual-operated rubber roller sheeting machine within the last two decades into a motorized rubber roller sheeting machine should re-ignite the activities of RSS in the rubber industry in Nigeria, especially within the small-holder rubber farmer. Higher-valued ribbed smoked rubber sheet production using motorized sheeting machines presents better economic opportunities, improved storage duration, and reduced rubber quality compromise to almost zero in Nigeria. It is hoped that the successful completion of this project will improve the overall smallholder farmers’ profitability and productivity of natural rubber in Nigeria. Consequently the objective of this paper is to evaluation the physicochemical properties, drying process and drying conditions of natural rubber (NR) latex and ribbed smoked sheets (RSS) obtained from Benin City, Nigeria

MATERIALS AND METHODS

*Study Area***:** The study was conduct at the Rubber Research Institute of Nigeria (RRIN), Benin City, Nigeria. It is located at Latitude 6^0 9’26.4” and Longitude 5^0 35’28.4” with an average elevation of

27.0 m above sea-level. The area is characterized with two seasons; the rainy season which begins in April and ends in October while the dry season expands between November – March yearly.

Materials: Field latex from the *Hevea brasiliensis* clones of NIG 800 series were obtained by the S2 d/2 (tapping half of the spiral once in two days frequency) tapping system from the estates of the Rubber Research Institute of Nigeria. The latex was transferred from the field to the latex processing centre. Analysis of the latex was carried out immediately after collection. The rubber sheets processing lohashilpi machine and coagulation aluminium pans with a 30 cm x 40 cm x 6 cm dimension were used for the production of the sheets. Formic acid (100%) and calcium carbonate were industrial grade and were used without further purification.

Standardized field latex: The field latex (50 L) was sieved with 40 – 60 mm mesh, to remove dirt and placed in a dilution drum. The dry rubber content of the latex was determined. The latex was standardized (Equation 1) by adding 92.4 L of water to increase the fluidity of the NR latex. Thereafter, 10.24 liters of 0.5% formic acid solution were added to the standardized latex and mixed thoroughly.

The amount of water (Ш) required in achieving the 12.5% standard dilution of DRC from the field latex and the volume of final standard latex (V) were calculated as equation 1:

$$\text{Ш} = (V - v)\ liters \quad (1)$$

The volume of final standard latex (V) calculated as presented in equation 2:

$$V = \frac{(d\ x\ v)}{D} \quad (2)$$

Where volume of field latex in liters *(v); D* = standard DRC (12.5 %), d = dry rubber content (DRC) of field latex.

Ribbed Smoked Sheets Production: Four liters of the acidified, standardized diluted latex from the bulk were separately poured into each coagulating pan. The filled aluminum pans were arranged in the processing room and left for 24 hours to coagulate. A whitish, semi-solid coagulum was obtained from the aluminum pan and fed into a motorized sheeting machine through a cleaned horizontal feeding tray. Each coagulum passed and rolled through a set of four pairs of rollers, of which the last pair was spirally grooved, resulting in wet, whitish ribbed sheets. The ribbed sheets were received in a bowl of fresh water and thoroughly rinsed with water after sheeting to remove residual acid. The rinsed, wet, groovy-surfaced ribbed sheets were placed on a drip-drying hanger under (Figure 1) shade for 2-4 hours and were protected from direct exposure to sunlight to prevent tackiness. The dripped-dried sheets were thereafter transferred into the smokehouse for drying.

Smoking: The smoke house (oven) is equipped with five layers of angers and a furnace which supplied heat into the smoked room. The smoke house provides heat at a regulated drying temperature of approximately 60 °C. The dripped dried sheets were placed on wooden rippers (sheet holders) and arranged on a hanger. The capacity of the RRIN smoke room is 560 sheets per batch.

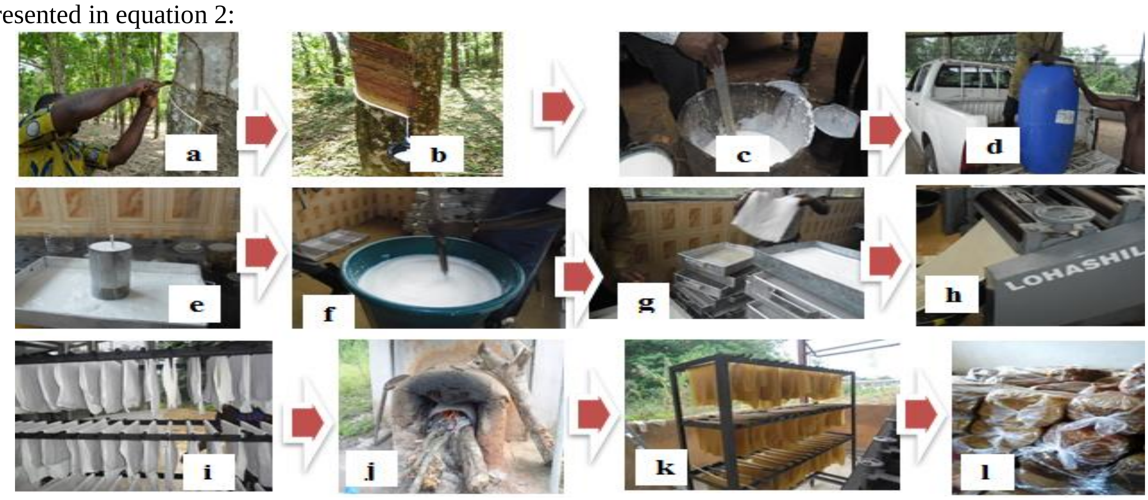

Fig 1. Field latex processing into ribbed smoked sheets in RRIN (Images; a - tapping of rubber tree, b - collection of NR latex, c - bulking of field latex, d- transportation of field latex to the processing factory, e- determination of DRC with metrolac. f- Dilution of latex and

acidification, g- coagulation, h- sheeting of coagulum, i- drip drying of rubber sheets, j- smoking of rubber sheets, k- ribbed smoked sheets and l- bales of rubber sheets.

The drying sheets are turn at interval of 20 hours in the smoke room to enable even drying of the sheets. The drying process is maintained for four days at approximately 60 ^{0}C to attain constant dried sheets weight.

Packaging and Storage studies: The RSS produced were sorted manually by grading on a scale of one to five *ie* RSS1, RSS2, RSS3, RSS4, and RSS5 (Pornpanomchai and Chantharangsikul 2010). Samples from the sorted sheets were lightly rubbed with $CaCO_3$ on both surface, arranged and packed into bales (10kg each per bale). The baled sheets were wrapped with a thin polythene film bags and stored which can later be dispatched for sale. The baled RSS were stored in a well aerated and ventilated section of the processing factory. This storage section was covered with iron nets to prevent rodent and insect. The control test samples (RSS without $CaCO_3$) were packed and kept in the same environment in absent of $CaCO_3$. The bales were arranged in open factory.

Physical and chemical characterization: The physicochemical properties, like the dry rubber content was determined by ISO R126 method, total solid content (ISO 124: 2014), the Mechanical stability time (ISO 35 of 1989), The nitrogen content (NC) (ISO 1656(E)) and Volatile fatty acids (ISO 506 of 1992) were determined by International Standard methods.

RESULTS AND DISCUSSION

Characterization of natural rubber field latex: The field latex collected is a whitish milky liquid with average dry rubber content (DRC) of 35.6 % hydrocarbon. The physical and chemical properties of field latex are presented in Table 1. The total solid content, mechanical stability time, and volatile fatty acids obtained in this study compare well with the results of *Hevea latex* reported by other workers in the literature. Other non-rubber constituents in the latex were responsible for the differences observed in the values of the TSC and DRC reports in Table 1.Proteins, carbohydrates, amino acids, lipids and minerals are present in relatively negligible amounts and constitute the non-rubber components that serve as a good medium for microbial growth (Salomez, Subileau *et al*. 2014). The presence of these components promotes bacteria and yeast multiplication in the latex thereby increasing the production of acids such as formic acid (Salomez, Subileau *et al*. 2014). The acid produced transforms the natural rubber latex into coagula. Pajarito*et. al.* showed that the volatile compounds (e.g., acids) produced during the microbial degradation of carbohydrates and proteins in the presence of minerals generate an offensive odour, which is characteristic of field latex coagulation (Pajarito *et al*. 2018).

Table 1: Composition of *Hevea* latex.

Constituents	Values
Dry rubber content (%)	35.60
Lipids (%)	1.08
Protéines (%)	1.23
Carbohydrates (%)	1.40
Minerals (%)	0.47
Water (%)	60.22
Specific gravity (28 °C)	0.931± 0.003
Total solid content (TSC) (%)	43.20 ± 1.03
Mechanical stability M.S.T (%)	650 ± 1.06
Volatile fatty acids VFA (%)	0.18 ±0.07
Nitrogen Content (%)	0.55 ± 0.03

The standardized latex coagulated was processed into sheets using motorized sheeting machine. The average rubber sheet production rate using the motorized lohalshipi sheeting machine used in this work was 340 (±74) sheets per hour with an average wet weight of natural rubber coagulum of 0.899 (±0.117) kg (Table 2). The average machine utilization is 12.5 % on the basis of daily production. During the drying process of the rubber sheets, the temperature of the smoke was maintained at approximately 60 ^{0}C. However, the temperature distributions within the planes in the smoke room were almost uniform with a slight variation of ± 5 ^{0}C. On drying, the sheets were almost rectangular, measuring approximately 30 cm (breath) by 50 cm (length) and 2.00 mm thick.

Table 2: Drying properties of RSS

Parameters	Values
Initial Weight of Wet Sheets (g)	899.86
Final Weight of Ribbed smoked Sheets (g)	567.24
Drying temperature (^{c}o)	60 ± 5
Average drying period (days)	4
Moisture content by weight %	36.96

Drying agricultural products is an age-long preservation technique that involves simultaneous heat and mass transfer of free moisture from the product. The average dried weight of ribbed smoked sheets obtained in this study is 567.24 g. The capacity of the RRIN smoke house per batch on basis of the dried sheets was 560 sheets (approximately 280 kg) per batch. One production batch lasted for 4 days. These values is much lower compared to the capacity of a typical Thailand 1994 smoke house model with 1.5 tons rubbers sheets per batch (Purba 2009). The dried sheets produced were transparent and yellowish in color Figure 1. The sheets were easy to handle with an environmentally friendly aroma which can be easily transported due to its lighter weight and occupied less space for storage compared with original field latex and coagula (Mahmood, Sultan, and Miyazaki 2019). The RSS is yellowish light brown in colour (Figure 2). The brightly coloured sheets gave a characteristic nice aroma. Thus, the smoking processes imparted excellent flavour, aroma and colour to these sheets (Suñen, Fernandez-Galian, and Aristimuño 2001). Other physical properties presented in Table 3 compare well with those of the sheets reported in other rubber producing countries (Kurian and Mathew, 2011). We observed that smoking of the sheets carried out above the drying temperature and for a long time resulted in scorched dark brown sheets. However, smoking of the sheets below 55 °C resulted in a longer duration of drying in which fungus growth was observed in some cases.

Fig 2: Typical dried ribbed smoked sheet.

The RSS produced were sorted manually by visual inspection. The products obtained in this factory during the period are in three grades namely RSS1, RSS2 and RSS3 (Figure 3). The RSS1 obtained accounted for approximately 94% of the total production and are free from blemishes, rust, blisters, sand, dirty packing, microbial growth and any other foreign matter. On the other hand, RSS2 were sheets with less than 5 % of blisters and slightly brownish, and this grade accounted for 4.2 % of the total RSS production compared with RSS3 which represent 1.8 % of the total RSS production. The quality of RSS3 was lower compared with RSS1 and RSS2. RSS3 contains blisters, slightly scotched and possible light mold account for about 5 % of the total surface area and are lightly brown.

Table 3: Properties of ribbed smoked sheets.

Parameters		Values
Burnt sheets		No
Oxidised sport		No
Transluscent Stains		No
Blister		No
Over-smoked		No
Dirt % (wt)		0.15
Ash % (wt)		0.11
Wallatile matter % (wt)		0.38
Wallace plasticity	P_0	47
	PRI	74
Colour		Yellowish light brown

Storage studies of ribbed smoked sheets: Generally, rubber growing region in Nigeria is characterized with two seasons. Every year, the rainy season lasts from April to October, whereas the dry season lasts from November to March. Nevertheless, there are slight variations in the seasons' rainfall, relative humidity, and temperature. Therefore, the storage of RSS in normal local conditions is taken into account. The RSS were stored in a well-insulated and ventilated section of the processing factory. A detailed meteorological data measurement obtained during the period is presented in Table 4.

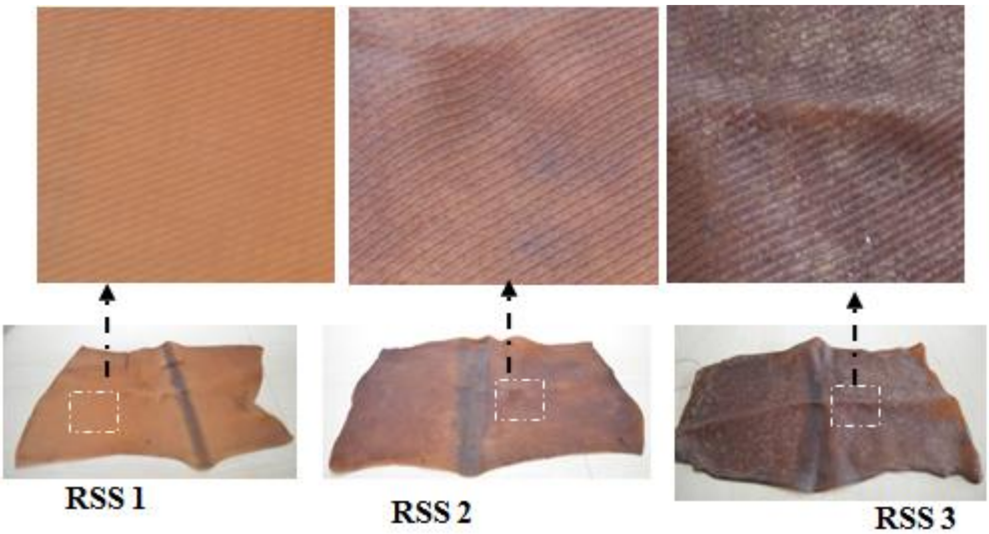

Fig 3: Three grades of sorted sheets RSS1, RSS2 and RSS3 (with corresponding expanded section below the samples).

During the storage period (January 2023 –September 2023), the temperature and relative humidity during the storage period ranged from 26.0 ^{0}C – 28.8 ^{0}C, and 60 % - 89 % respectively. These values compare well with the average daily temperature and relative humidity in Benin City reported by other workers (Ugwa *et al*., 2017). The rainfall during the storage period increases gradually over the months with July recording the highest rainfall.

The effect of storage duration on quality of RSS on different treatment was monitored. The results showed that RSS treated with $CaCO_3$ had no observable change in physical appearance over a period of seven months. However, fungi growth was observed on the control RSS after 4 months, compared with RSS dusted with $CaCO_3$ which appear after 7 months. The observed growth in untreated RSS spread over the entire surface within 30 days. Similarly, the fungi growth initiated after seven months in the treated RSS and spread over the entire sheets within 45 days. The brightly coloured yellowish-light-brown sheets begin to turn into brownish colour. Thereafter, the fungi spread over the entire surface of RSS in both treatments. Similarly, the flavour and aroma imparted on RSS after smoking begins to reduce on full spreading of fungi.

Table 4: Mean monthly weather report

Month	Rainfall (mm)	Humidity %	Temperature ^{0}C
Jan	11.5	67	27
Feb	65.1	60	29
Mar	80.8	75	29
Apr	277.9	78	28
May	237.9	82	27
Jun	292.9	85	25
Jul	378.1	86	25
Aug	286.1	89	26
Sep	368.9	90	26
Oct	222	81	29
Nov	97.1	67	29

Thus, RSS undergo colour and flavour changes to varying degrees on storage with time. The application of carbonate enhances their durability during storage. The results obtained from this study showed that there is a save period of 7 months for the storage, transportation and utilization of RSS treated with $CaCO_3$ for product formation. After this period, deterioration in the quality of RSS was experienced as from the eight month. The appearance of the RRS after 8 month is shown in Figure 4. Ghaemmaghami *et al*. suggested that the presence of *Aspergillus* might potentially lead to mycotoxin production when processes of storage and transportation are not appropriate. This observation might have been responsible for brownish change in coloration observed (Ghaemmaghami, Nowroozi, and Tohidi moghadam 2018).

These results revealed that smoke drying of rubber sheets inhibit the growth microorganism on stored products. Similarly, the addition of $CaCO_3$ before package further prolongs the shelf life of the RSS. The results obtained from this study showed that NR ribbed smoked sheets can be stable for eight months in moderately moist and humid climates if they are properly dried, packaged, and stored. The ability to store the sheets for longer period will help to alleviate the challenge where small holders of rubber sell their products at discounted prices. Small-holder rubber farmers can distribute or sell to buyers without fear of degradation within a considerable period where the sheets retain its high quality until it is used. The period also allows shipping, storage and final utilization of the product. The current study gave insight on storage durability, stability and the shelf of RSS in a typical small holder famer's environment. It therefore implies that the smallholder farmers have a reasonable holding time within wish their product can be transported from the farm to the buyer at appropriate price without the fear of getting bad.

Conclusion: Ribbed smoked sheet can be used for the production of rubber-based goods like tires, condoms, surgical gloves, balloons, adhesive, rubber bands, latex foam, etc. The sheets are produced through the tapping process, latex collection, filtration, dilution, coagulation, sheeting, and smoke drying, which can be completed within 4 days. The results from this study revealed that smoke drying using wood not only inhibits the growth of microorganisms on stored products but also imparts

Fig 4: RSS stored after 10 months of production

flavour, good aroma, and color to the sheets in addition to serving as a preservative. Similarly, the addition of $CaCO_3$ further prolongs the shelf life of the product. Alternative drying methods for smoked sheets, like solar energy and biofuels, might be the subject of future research. The high-quality ribbed smoked sheet market suggests a bright future for the rubber products industry as an excellent value addition process that could attract desirable economic benefits to smallholder farmers.

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Data Availability Statement: Data are available upon request from the author.

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