



Impact of the Tajogaite Volcano eruption on symptoms and pulmonary function in a paediatric population

Valle Velasco ¹, David Díaz Pérez ^{2,3,4}, Enrique González-Dávila⁵, Julia Gavilán ¹,
Alberto Ruano-Ravina ^{6,7}, Cristina Candal-Pedreira ^{6,7}, Germán Peces-Barba^{8,9},
Esther Barreiro ^{9,10,11,12}, Ana Cañas-Portilla¹³, María Jesús Cruz Carmona^{9,14}, Xavier Muñoz^{9,14},
Francisco Javier Sánchez-Íñigo¹³ and Ciro Casanova^{2,3,9}

¹Paediatric Pulmonology, Canary Islands University Teaching Hospital, Universidad de La Laguna, Santa Cruz de Tenerife, Spain. ²Pulmonary Department, Research Unit, Hospital Universitario Ntra. Sra. de La Candelaria, Universidad de La Laguna, Santa Cruz de Tenerife, Spain. ³Canary Islands Health Research Institute Foundation (FIISC), Las Palmas de Gran Canaria, Spain. ⁴Department of Nursing, Universidad de la Laguna, Santa Cruz de Tenerife, Spain. ⁵Departamento de Matemáticas, Estadística e Investigación Operativa, Instituto IMAULL, Universidad de La Laguna, Santa Cruz de Tenerife, Spain. ⁶Department of Preventive Medicine and Public Health, University of Santiago de Compostela, Santiago de Compostela, Spain. ⁷Health Research Institute of Santiago de Compostela, Santiago de Compostela, Spain. ⁸Department of Pulmonology, Jiménez Díaz Foundation University Teaching Hospital, Madrid, Spain. ⁹Consortium for Biomedical Research in Respiratory Diseases (CIBERES), Madrid, Spain. ¹⁰Muscle Wasting and Cachexia in Chronic Respiratory Diseases and Lung Cancer Research Group, Hospital del Mar Research Institute, Barcelona, Spain. ¹¹Pulmonology Department, Hospital del Mar, Barcelona, Spain. ¹²Department of Medicine and Life Sciences, Pompeu Fabra University, Barcelona, Spain. ¹³National Centre for Environmental Health, Instituto de Salud Carlos III, Majadahonda, Spain. ¹⁴Department of Pulmonology, Vall d'Hebron Hospital, Barcelona, Spain.

Corresponding author: Ciro Casanova (casanovaciro@gmail.com)



Shareable abstract (@ERSpublications)

Respiratory symptoms were frequently observed in children and adolescents living in areas with high exposure to volcanic emissions. D_{LCO} and F_{ENO} may help identify abnormalities despite normal spirometry in this population. <https://bit.ly/4dmo9eZ>

Cite this article as: Velasco V, Díaz Pérez D, González-Dávila E, *et al.* Impact of the Tajogaite Volcano eruption on symptoms and pulmonary function in a paediatric population. *ERJ Open Res* 2026; 12: 00401-2026 [DOI: 10.1183/23120541.00401-2026].

Copyright ©The authors 2026

This version is distributed under the terms of the Creative Commons Attribution Non-Commercial Licence 4.0. For commercial reproduction rights and permissions contact permissions@ersnet.org

Received: 17 March 2026
Accepted: 10 May 2026

Abstract

Rationale The Tajogaite Volcano (La Palma, Spain) erupted in September 2021 for 85 days, releasing gases, ash and lava over populated areas. Data on the respiratory effects of volcanic emissions in children remain limited. The aim of the present study was to describe the prevalence of respiratory symptoms and lung function patterns in a paediatric population exposed to emissions from the Tajogaite Volcano.

Methods A cross-sectional study with a follow-up component was conducted in a high-exposure area. A total of 188 children aged 6–18 years were interviewed 10–17 months after the eruption. Sociodemographic data, medical history and symptom records during and after the eruption were collected. Post-eruption lung function was assessed using spirometry, diffusing capacity of the lung for carbon monoxide (D_{LCO}) and exhaled nitric oxide fraction (F_{ENO}).

Results During the eruption, 25–50% of participants reported respiratory symptoms, mainly in the upper airway (itching and nasal congestion). Post eruption, ocular symptoms decreased ($p < 0.05$), whereas cough, headache, nasal congestion, sore throat and skin problems persisted. Symptom frequency and persistence were higher among children with a history of asthma or environmental tobacco smoke exposure ($p < 0.05$). Post eruption, 6.4% of participants had reduced forced expiratory volume in 1 s and/or reduced forced vital capacity, 15.2% showed decreased D_{LCO} (below the fifth percentile according to the Global Lung Function Initiative reference equations) and 44% had $F_{ENO} \geq 20$ ppb.

Conclusions Children and adolescents exposed to the Tajogaite Volcano eruption presented a high prevalence and persistence of respiratory symptoms, particularly those with environmental tobacco smoke exposure or underlying respiratory conditions. Including D_{LCO} and F_{ENO} in spirometric evaluation may help detect respiratory abnormalities and support further longitudinal monitoring.



Introduction

Volcanic eruptions are a relatively rare natural phenomenon that can impact public health. Airborne emissions of respirable ash particles, aerosols and gases can affect the health of living beings (both humans and animals), although scientific evidence remains very limited [1–3]. Moreover, detailed exposure measurements from such events are rarely documented and scarcely accessible.

Scientific evidence regarding the effects of exposure to volcanic emissions in paediatric populations reveals heterogeneous findings across various geographical contexts. Several studies evaluating lung function parameters through forced spirometry in children exposed to volcanic ash have not demonstrated significant declines in respiratory function or increases in asthma prevalence [4–7]. However, a trend towards a reduction in the forced expiratory volume in 1 s (FEV₁)/forced vital capacity (FVC) ratio has been identified in cases of chronic exposure to acidic respirable particles [8]. In addition, other studies analysing hospital records have reported increased rates of asthma-related hospitalisations during periods of elevated ash density [9], as well as more incidences of respiratory illnesses following volcanic eruptions [10]. Furthermore, significant associations have been described between exposure to airborne particles and gases, including sulfur dioxide (SO₂), and the occurrence of respiratory symptoms, ocular disturbances and disruptions in sleep patterns and behaviour [11–13].

On 19 September 2021, the Tajogaite Volcano (also known as Cabezavaca), located in Cumbre Vieja Natural Park on La Palma, Canary Islands, Spain, began erupting. During the 85 days of the eruption, intense emissions of lava, ash and gases of varying composition were released. In October 2021, the Spanish Society of Pneumology and Thoracic Surgery (Sociedad Española de Neumología y Cirugía Torácica (SEPAR)) decided to sponsor the Analysis of Exposure and Respiratory Health Effects of Volcanic Eruption in the Canary Islands (ASHES) study. Previous findings from the adult cohort of the ASHES study documented an increase in respiratory symptoms associated with the eruption, including a previously unreported dose–response relationship, and a trend towards declining pulmonary function with increasing exposure [14]. Our objective was to describe the prevalence of respiratory symptoms and lung function patterns in this high-exposure area, under the hypothesis that children may represent a vulnerable group susceptible to volcanic emissions.

Methods

Participants recruited to the study

The ASHES project is a multidesign study conducted on La Palma (Spain) [15]. A central mountain range divides the territory from north to south, and the eruption in the south-west allowed classification of populations by exposure level. This study was limited to the high-exposure area of Valle de Aridane, including Los Llanos de Aridane, El Paso and Tazacorte (figure 1).

The study employed non-probabilistic convenience sampling, recruiting paediatric participants through collaboration with schools in the affected municipalities. Participation was voluntary, requiring students and their legal guardians to receive a school information letter and provide informed consent.

Inclusion criteria were age <18 years, residence in one of the selected municipalities during the eruption period and absence of acute respiratory infections in the 2 weeks prior to evaluation. Exclusion criteria included inability to obtain technically acceptable spirometry.

The protocol was approved by the Ethics Committee for Research with Medicines of the University Hospital Complex of the Canary Islands on 10 March 2022. Written informed consent was obtained from the legal guardians of all participating minors, ensuring confidentiality in accordance with the General Data Protection Regulation (EU 2016/679) and Organic Law 3/2018 on Protection of Personal Data and Guarantee of Digital Rights.

Clinical and physiological measurements

The methods of the ASHES study have been published previously [15]. In summary, interviews were conducted 10–17 months after the volcanic eruption ended to collect information reported by both the parents of the minors and the minors themselves. A structured questionnaire was administered in person by trained personnel. These personnel were nursing staff specifically trained by nurses specialised in the use and interpretation of respiratory function tests. The questionnaire included sociodemographic variables, personal medical history, household characteristics, exposure to volcanic emissions (including time spent outdoors, types of activities performed and protective measures adopted) and tobacco smoke exposure. The questionnaire also collected information on the presence of symptoms during three distinct periods: during the eruption; after the eruption (defined as 3–4 months after its end); and in the month preceding the interview, which was conducted 10–17 months after the eruption. Reported symptoms were categorised as general (headache, throat irritation, odynophagia), ocular (tearing, eye itching), respiratory (nasal itching,

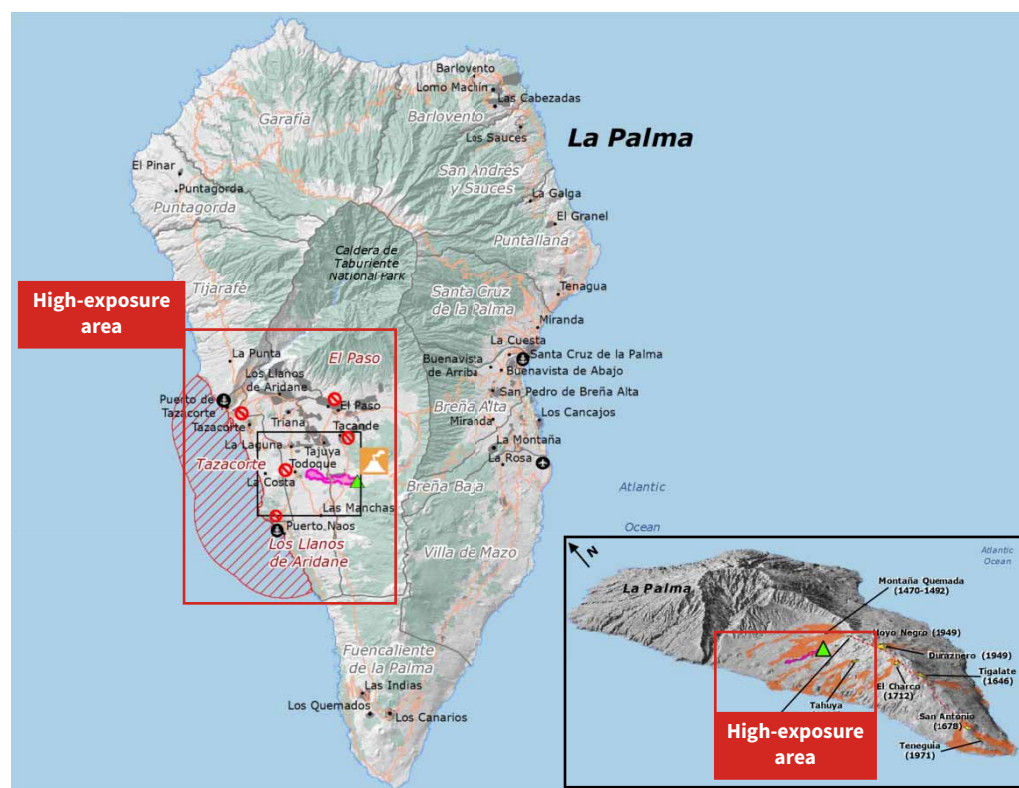


FIGURE 1 Map of La Palma illustrating the delineated high-exposure zone associated with the Tajogaite volcanic eruption. Adapted from the Emergency Response Coordination Centre, available at <https://erccportal.jrc.ec.europa.eu/ECHO-Products/Maps#/maps/3850>.

nasal congestion, cough, dyspnoea, chest tightness) or cutaneous (skin problems). This questionnaire is based on the 2019 guidelines of the International Volcanic Health Hazard Network for conducting epidemiological studies related to volcanic eruptions. In addition, validated questionnaires were used to ascertain respiratory symptoms (European Community Respiratory Health Survey/ECRHS III) [16].

Pulmonary function tests – pre-bronchodilator spirometry, diffusing capacity of the lung for carbon monoxide (D_{LCO}) and exhaled nitric oxide fraction (F_{ENO} , measured with an electrochemical sensor device: Evernoa Base, everSens SL, Spain) – were performed in accordance with SEPAR and European Respiratory Society (ERS)/American Thoracic Society (ATS) 2022 quality standards [17].

Statistical analysis

Data were summarised as relative frequencies for categorical variables, mean (standard deviation) for normally distributed variables and median (25th–75th percentile) for non-normal data. As appropriate, comparisons were made using Pearson's chi-squared test for categorical variables, the Kruskal–Wallis H test or the Mann–Whitney U test for non-normally distributed data and one-way ANOVA or t-test for normally distributed continuous variables. Correlations were estimated using Spearman's or Pearson's linear coefficients. FEV_1 %, FVC % and D_{LCO} % were considered abnormal if values fell below the 5th or 10th percentile of the lower limit of normal according to Global Lung Function Initiative (GLI) reference equations. $F_{ENO} \geq 20$ ppb was considered abnormal, guided by ATS clinical practice guidelines [18] and recent large-scale studies in healthy populations [19]. For the analysis of the temporal evolution of symptoms, we used a generalised linear mixed model with a binary logistic regression. Statistical significance was set as a two-tailed p-value < 0.05 . Calculations were made with SPSS 29.0 (IBM SPSS, Armonk, NY).

Results

Characteristics of ASHES paediatric participants

The study population comprised a total of 188 individuals: 99 (52.7%) males and 89 (47.3%) females, with a mean age of 10.7 years (SD 2.7), ranging from 6 to 17 years. Table 1 shows the baseline

TABLE 1 Baseline characteristics and pulmonary function in the paediatric Analysis of Exposure and Respiratory Health Effects of Volcanic Eruption in the Canary Islands (ASHES) study participants, stratified by sex

	Sex		p-value	Total (n=188)
	Male (n=99)	Female (n=89)		
Age, years	10.6±2.7	10.7±2.8	0.756	10.7±2.7
Age, n (%)			0.688	
<14 years	85 (86)	74 (83)		159 (85)
≥14 years	14 (14)	15 (17)		29 (15)
BMI, kg·m ⁻²	20.2±5.0	19.9±5.3	0.681	20.0±5.1
Environmental tobacco smoke exposure (car and/or home), n (%)	14 (14.1)	11 (12.4)	0.831	25 (13.3)
Parental history of asthma/COPD/lung cancer, n (%)	31 (31.3)	23 (25.8)	0.425	54 (28.7)
Medical history, n (%)				
Rhinitis	25 (25)	12 (14)	0.128	37 (20)
Asthma	9 (9.1)	8 (9.0)	0.981	17 (9.0)
Pneumonia	9 (9.1)	8 (9.0)	0.981	17 (9.0)
Pulmonary function				
S _{pO₂} , %	98.1±0.9	98.4±0.8	0.064	98.3±0.9
FEV ₁ , %	102.3±10.4	98.1±12.8	0.015	100.3±11.7
FVC, %	102.8±11.0	99.7±12.9	0.073	101.3±12.0
FEV ₁ /FVC, %	85.9±6.5	87.7±6.9	0.065	86.7±6.8
Z-score, median (IQR)			0.134	
FEV ₁	0.23 (−0.44–0.79)	0.03 (−0.54–0.59)		0.16 (−0.47–0.71)
FVC	0.17 (−0.44–0.78)	−0.01 (−0.78–0.67)	0.100	0.09 (−0.55–0.76)
FEV ₁ or FVC<GLI 5%, n (%)	4 (4.0)	8 (9.0)	0.233	12 (6.4)
FEV ₁ or FVC<GLI 10%, n (%)	7 (7.1)	14 (15.7)	0.067	21 (11.2)
F _{ENO} , ppb	23.6±21.4	22.8±21.3	0.821	23.3±21.3
F _{ENO} , ppb, median (IQR)	19 (12–32)	16 (11–28)	0.313	18 (11–30)
F _{ENO} ≥20 ppb, n (%)	41 (47.1)	28 (40.0)	0.420	69 (43.9)
Z-score D _{LCO} , median (IQR)	−0.49 (−0.83–0.23)	−0.55 (−0.91–−0.17)	0.314	−0.50 (0.85–0.02)
D _{LCO} <GLI 5%, n (%)	8 (11.9)	9 (20.0)	0.288	17 (15.2)
D _{LCO} <GLI 10%, n (%)	9 (13.4)	9 (20.0)	0.434	18 (16.1)

Data are presented as mean±SD unless otherwise stated. D_{LCO}, n=112 participants; F_{ENO}, n=157 participants. BMI: body mass index; S_{pO₂}: peripheral oxygen saturation; FEV₁: forced expiratory volume in 1 s; FVC: forced vital capacity; IQR: interquartile range; GLI: Global Lung Function Initiative; F_{ENO}: exhaled nitric oxide fraction; D_{LCO}: diffusing capacity of the lung for carbon monoxide.

characteristics of paediatric participants and their pulmonary function after the volcanic eruption. No significant differences were observed between sexes in any of the recorded variables.

4% of the cohort reported maternal smoking during pregnancy, and 13.3% had exposure to environmental tobacco smoke; only one individual reported active smoking. Hospital admission at birth occurred in 22 participants (16%), 22% of whom were admitted for respiratory causes. Regarding respiratory history, 20% had a prior diagnosis of rhinitis and 9% had asthma.

At the onset of the eruption (September 2021), 29% of the study population was evacuated from their homes. These evacuations were primarily driven by lava flow hazards; consequently, most displaced families were relocated to emergency shelters or temporary housing within the Aridane Valley, which remained a high-exposure area. Only 3.5% of the total cohort relocated to low-exposure areas of the island for a limited period of 1–4 months.

Symptom reporting by periods

Figure 2 shows the progression of symptoms recorded across the three previously defined time periods: during the eruption, after the eruption and in the month preceding the interview. The symptoms showing the greatest decline since the eruption were itchy eyes ($p<0.001$) and tearing ($p=0.022$). Symptoms that remained stable in frequency throughout the study period included cough, chest tightness, headache, nasal congestion, sore throat and skin problems (figure 2).

Table 2 describes the temporal evolution of symptoms in children with a prior respiratory history, including asthma and exposure to environmental tobacco smoke. Overall, symptoms were more frequent in

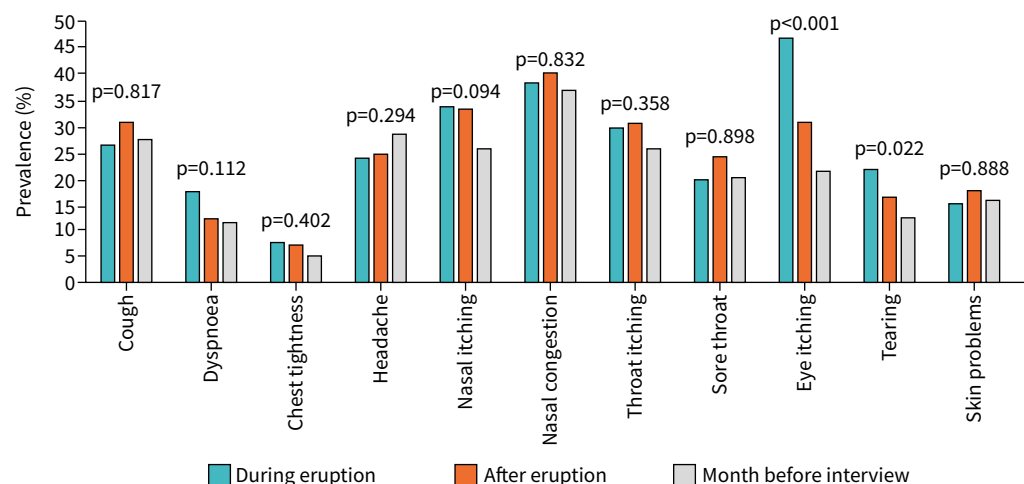


FIGURE 2 Prevalence of symptoms reported during the Tajogaite volcanic eruption, after the eruption and in the month preceding the interview (10–17 months post eruption).

those with any of these pre-existing conditions. The impact of prior asthma gradually decreased over time, with environmental tobacco smoke exposure remaining the only significant risk predictor.

Lung function

FEV₁ % or FVC % was below the GLI 5th percentile in 12 participants (6.4%), increasing to 11.2% when using the GLI 10th percentile. D_{LCO} , available for 111 participants, was below the GLI 5th and 10th percentiles in 15.2% and 16.1%, respectively (table 1). No significant associations were observed with environmental tobacco smoke exposure ($p=0.736$) or asthma ($p=0.388$).

F_{ENO} was measured in 157 participants, and 44% had values at or above the previously established threshold of 20 ppb. No significant differences were observed between participants with and those without a prior asthma diagnosis ($p=0.779$). However, in the post-eruption period, elevated F_{ENO} values were associated with nasal congestion and nasal and ocular itching ($p<0.01$), and showed a nonsignificant trend towards association with cough ($p=0.063$; table S1).

98 participants underwent all three respiratory tests. Using the GLI 5th percentile, concordant impairment across all tests was observed in only 2.3% of participants, rising slightly to 4.5% with the 10th percentile. Considering only spirometric impairment combined with D_{LCO} , the proportion increased, but remained low (7.1% and 21.4% for the 5th and 10th percentiles, respectively). The overlaps of impairments are shown in Venn diagrams (figure S1).

Discussion

The main findings of this study in children and adolescents exposed to the 2021 Tajogaite volcanic eruption can be summarised as follows: 1) a high proportion of participants reported upper respiratory and ocular symptoms during the eruption and in the subsequent months; 2) pulmonary symptoms were more frequent among individuals with a prior history of asthma or exposure to environmental tobacco smoke; 3) the temporal pattern of symptom recovery was heterogeneous, with symptoms persisting longer in those exposed to environmental tobacco smoke; and 4) a small proportion of the evaluated population showed impaired pulmonary function on spirometry, with a higher prevalence of abnormalities observed in D_{LCO} values. In addition, a considerable proportion of participants exhibited elevated F_{ENO} levels, including children without a previous diagnosis of asthma.

Volcanic emissions exposure and physical symptoms

Our findings regarding symptom prevalence are consistent with previous studies conducted during other volcanic eruptions, which similarly reported increases in respiratory, ocular and cutaneous symptoms both during the eruption and in the months following its cessation [7, 12, 13, 20]. Nevertheless, the temporal patterns of symptoms described in the literature appear highly heterogeneous.

TABLE 2 Symptom evolution during the eruption, after the eruption and in the month preceding the survey (10–17 months post eruption), by personal history of environmental tobacco smoke exposure and asthma

	Exposure to environmental tobacco smoke			Asthma		
	No (n=163)	Yes (n=25)	p-value	No (n=171)	Yes (n=17)	p-value
During eruption						
Cough	39 (24)	11 (44)	0.034	43 (25)	7 (41)	0.129
Dyspnoea	24 (15)	9 (36)	0.014	26 (15)	7 (41)	0.015
Chest tightness	10 (6)	4 (16)	0.097	9 (5)	5 (29)	0.004
Headache	34 (21)	11 (44)	0.015	37 (22)	8 (47)	0.025
Nasal itching	50 (31)	14 (56)	0.013	53 (31)	11 (65)	0.007
Nasal congestion	55 (34)	17 (68)	0.001	65 (38)	7 (41)	0.495
Throat itching	42 (26)	14 (56)	0.003	49 (29)	7 (41)	0.209
Sore throat	28 (17)	9 (36)	0.032	31 (18)	6 (35)	0.089
Eye itching	72 (44)	16 (64)	0.064	76 (44)	12 (71)	0.035
Tearing	32 (20)	9 (36)	0.065	34 (20)	7 (41)	0.049
Skin problems	21 (13)	8 (32)	0.021	23 (14)	6 (35)	0.029
After eruption						
Cough	46 (28)	12 (48)	0.042	50 (29)	8 (47)	0.109
Dyspnoea	17 (10)	6 (24)	0.062	17 (10)	6 (35)	0.009
Chest tightness	9 (6)	5 (20)	0.024	10 (6)	4 (24)	0.026
Headache	35 (22)	12 (48)	0.006	42 (25)	5 (29)	0.426
Nasal itching	47 (29)	15 (60)	0.003	53 (31)	9 (53)	0.062
Nasal congestion	60 (37)	16 (64)	0.01	68 (40)	8 (47)	0.368
Throat itching	45 (28)	12 (48)	0.036	51 (30)	6 (35)	0.413
Sore throat	35 (22)	10 (40)	0.043	40 (23)	5 (29)	0.384
Eye itching	46 (28)	12 (48)	0.042	49 (29)	9 (53)	0.04
Tearing	26 (16)	5 (20)	0.571	26 (15)	5 (29)	0.125
Skin problems	25 (15)	8 (32)	0.045	29 (17)	4 (24)	0.346
Month preceding survey						
Cough	40 (25)	12 (48)	0.016	46 (27)	6 (35)	0.316
Dyspnoea	15 (9)	7 (28)	0.014	17 (10)	5 (29)	0.033
Chest tightness	6 (4)	4 (16)	0.03	8 (5)	2 (12)	0.225
Headache	41 (25)	13 (52)	0.007	48 (28)	6 (35)	0.354
Nasal itching	36 (22)	13 (52)	0.003	43 (25)	6 (35)	0.26
Nasal congestion	55 (34)	15 (60)	0.012	62 (36)	8 (47)	0.266
Throat itching	37 (23)	11 (44)	0.025	43 (25)	5 (29)	0.447
Sore throat	29 (18)	9 (36)	0.038	33 (19)	5 (29)	0.241
Eye itching	30 (19)	10 (40)	0.018	35 (21)	5 (29)	0.28
Tearing	19 (12)	5 (20)	0.329	21 (12)	3 (18)	0.373
Skin problems	22 (14)	8 (32)	0.026	27 (16)	3 (18)	0.532

Data are presented as n (%) participants. Bold p-values indicate statistical significance.

This study describes a high prevalence and persistence of respiratory symptoms in the short- to medium-terms following the eruption, in line with previous reports in other paediatric populations. This finding was more pronounced among children with a history of asthma. Although this pattern might be theoretically expected and has been described in some case reports [9, 21], it remains controversial. Indeed, it was not observed in evaluations of children following the Mount St. Helens eruption [22] or in the more recent analysis of SO₂ exposure from the Kilauea Volcano [8]. Such discrepancies could be related to differences in exposure characteristics and to specific features of the Tajogaite Volcano on La Palma, including its close proximity to populated areas. Moreover, variability in self-reported asthma diagnoses in survey data cannot be excluded [23].

Another important finding of this study is the observation that children exposed to environmental tobacco smoke reported an increase in respiratory symptoms during the volcanic eruption, and that these children also tended to show more persistent symptoms in the post-eruptive period. Although some recent studies have incorporated this variable into their questionnaires [8], to our knowledge, the present study is the first to describe its potential role in relation to respiratory symptom patterns following a volcanic eruption.

Approximately 60% of participants reported eye itching, with a marked decrease observed in the post-eruptive period. These results are consistent with the findings of KIMURA *et al.* [12], whose study had a similar design in terms of both the type of volcanic particles emitted (ash with a high concentration of crystalline silica) and the proximity of the exposed population. In contrast to the Japanese study, our work is less influenced by urban pollution, as the populations on La Palma are small and background levels of traffic-related and other anthropogenic pollutants are low, and our work also provides data on the temporal evolution of ocular symptoms during the 10–17 months following the eruption. Furthermore, in the case of La Palma, there may have been an additive effect of ambient SO₂ concentrations, which have been associated with ocular irritation in studies conducted in adult populations [24].

Finally, it is important to acknowledge the role of potential confounding factors in the reported symptomatology. Psychological stress associated with the eruption, mass evacuations and uncertainty could have influenced symptom perception or contributed to psychosomatic or stress-related responses.

Volcanic emissions exposure and lung function

Only a small proportion of our study population demonstrated reduced spirometric values. This finding is consistent with previous reports, including from JOHNSON *et al.* [4], who studied children aged 9–11 years exposed to ash from the Mount St. Helens eruption, and IWASAWA *et al.* [7], who evaluated a paediatric cohort aged 6–18 years exposed to SO₂ from the Miyakejima Volcano in Japan.

In contrast, we observed a more pronounced impairment in D_{LCO} , with reductions occurring at twice the prevalence of spirometric abnormalities. To the best of our knowledge, this is the first study to incorporate D_{LCO} measurement in the respiratory assessment of children following a volcanic eruption. Notably, this discrepancy relative to spirometry was not observed in the recent adult analysis of the ASHES cohort [14]. These findings may suggest that, in children, inhalation of volcanic particles and gases may affect alveolar and/or pulmonary vascular structures that are more vulnerable to injury, and/or that such effects may occur at an earlier stage, prior to the onset of detectable changes in pulmonary flows or volumes. Moreover, differences between children and adults could be attributed to higher exposure in younger individuals: children have higher weight-adjusted minute ventilation, spend more time outdoors engaged in vigorous activities and, because of their shorter stature, inhale air closer to the ground level, where volcanic ash tends to accumulate. In addition, increased physiological vulnerability of the developing alveolar–capillary network, together with an immature immune system, may further increase susceptibility [25].

Another novel contribution of this study was the evaluation of F_{ENO} , which revealed elevated levels in approximately 44% of those tested. Interestingly, higher values were also observed in children without a history of asthma. This finding may appear to contradict the conventional interpretation of F_{ENO} as a primary marker of eosinophilic inflammation associated with T-helper 2 (Th2)-mediated allergic responses, typically observed in allergic rhinitis and asthma [26]. Our examinations were conducted between October and June, and elevated F_{ENO} levels were observed throughout this period, suggesting that seasonal allergen exposure alone may not fully explain these findings. However, increased F_{ENO} levels were associated with the presence of cough, nasal itching and congestion, which may suggest underdiagnosis of asthma. Nevertheless, accumulating evidence suggests that F_{ENO} may also reflect epithelial injury or dysfunction secondary to environmental exposures, including air pollutants and irritants [27], such as SO₂ released during volcanic eruptions. This may partly explain the elevated F_{ENO} levels observed in children without a history of atopy, as volcanic emissions could trigger airway inflammation through nonallergic pathways. Moreover, it is conceivable that children with a history of asthma, in addition to their use of inhaled corticosteroids, may have benefited from stricter protective measures (remaining indoors, mask use) implemented by their caregivers during and after the eruption.

Limitations and strengths

This study has several limitations. First, the cross-sectional design and the retrospective collection of symptom data preclude establishing causal relationships. Therefore, our findings should be interpreted as hypothesis-generating and support the need for future prospective research. Longitudinal follow-up of this cohort is currently ongoing. Furthermore, the recruitment window (10–17 months post eruption) introduces variability in recovery time. Consequently, participants assessed later in the study may have had more time for physiological recovery than those evaluated earlier, which may have influenced the observed prevalence of symptoms and functional outcomes. Second, the absence of a low-exposure control group precludes ruling out the potential influence of background respiratory morbidity, seasonal variation or post-pandemic trends on the observed outcomes. Third, reliance on self-reported (or caregiver-reported) symptoms introduces the potential for recall bias, which is inherent to all studies of volcanic eruptions using post-event questionnaires. Nevertheless, trained personnel collected all information and performed functional tests following

standardised procedures to minimise bias. Fourth, the relatively small sample size in subgroups of children with pre-existing respiratory conditions may limit statistical power and increase the risk of type II errors. Finally, the lack of pre-eruption pulmonary function data limits the quantification of individual changes. This limitation reflects real-life practice, as respiratory tests are not routinely performed in the general population – even among individuals with pre-existing respiratory conditions – particularly in less-resourced healthcare settings such as La Palma, and especially for highly specific assessments such as D_{LCO} and F_{ENO} .

The strengths of this study include the use of a well-characterised sample of children and adolescents directly exposed to a volcanic eruption with unique characteristics, such as proximity to densely populated areas, prolonged duration (85 days) and a setting largely free from confounding effects of urban pollution. In addition, the use of a questionnaire capturing symptoms at several time points during and after the eruption allowed the identification of temporal trends. Finally, the inclusion of pulmonary function testing enabled objective quantification of potential structural lung damage, and the novel incorporation of D_{LCO} and F_{ENO} , providing a more comprehensive assessment of different dimensions of pulmonary structure and function [2].

In conclusion, our findings describe an increase in symptoms associated with volcanic eruptions among children and adolescents, with a variable temporal pattern. Children with environmental tobacco smoke exposure and pre-existing respiratory diseases appear to be more vulnerable to both acute effects and symptom persistence. Assessment of pulmonary function by spirometry alone may underestimate lung damage related to volcanic exposure; the combined use of additional tools such as D_{LCO} and F_{ENO} may allow a more accurate assessment. However, further longitudinal studies are needed to better understand their significance and utility in the routine evaluation of this population. Taken together, these observations highlight the need for targeted surveillance and preventive strategies tailored to paediatric populations exposed to volcanic emissions.

Provenance: Submitted article, peer reviewed.

Ethics statement: The protocol was approved by the Ethics Committee for Research with Medicines of the University Hospital Complex of the Canary Islands on 10 March 2022. Written informed consent was obtained from the legal guardians of all participating minors, ensuring confidentiality in accordance with the General Data Protection Regulation (EU 2016/679) and Organic Law 3/2018 on Protection of Personal Data and Guarantee of Digital Rights.

We have used artificial intelligence solely to improve the grammatical aspects of the text.

Author contributions: The listed authors attest that they contributed substantially to the study's conception and design; acquisition, analysis and interpretation of the data; drafting the article or revising it critically for important intellectual content; and final approval of the version to be submitted for revision. All authors had full access to all the data in the study and accepted responsibility for submitting this work.

Conflict of interest: A. Ruano-Ravina, E. Barreiro and M.J. Cruz Carmona are serving editorial board members with *ERJ Open Research*. C. Candal-Pedreira reports receiving grants from SEPAR and the Instituto de Salud Carlos III; payment or honoraria for lectures, presentations, speakers' bureaus, manuscript writing or educational events from AstraZeneca; and leadership roles with *Archivos de Bronconeumología* and *Gaceta Sanitaria*, all disclosures made outside the submitted work. The remaining authors have nothing to disclose.

Support statement: The study was funded by an unrestricted grant from the Spanish Society of Pneumology and Thoracic Surgery (SEPAR) and Instituto de Salud Carlos III, grant PI24/01992. Funding information for this article has been deposited with the Open Funder Registry.

References

- 1 Hansell A, Horwell C, Oppenheimer C. The health hazards of volcanoes and geothermal areas. *Occup Environ Med* 2006; 63: 149–156.
- 2 Stewart C, Damby DE, Horwell CJ, *et al.* Volcanic air pollution and human health: recent advances and future directions. *Bull Volcanol* 2022; 84: 11.
- 3 Annesi-Maesano I, Bayram H, Cecchi L, *et al.* Natural disasters and respiratory health. *Eur Respir J* 2025; 66: 2402563. Erratum in: *Eur Respir J* 2025; 66: 2452563.
- 4 Johnson KA, Loftsgaarden DO, Gideon RA. The effects of Mount St. Helens ash on the pulmonary function of 120 elementary school children. *Am Rev Respir Dis* 1982; 126: 1066–1069.
- 5 Buist AS, Johnson LR, Vollmer WM, *et al.* Acute effects of volcanic ash from Mount Saint Helens on lung function in children. *Am Rev Respir Dis* 1983; 127: 714–719.

- 6 Uda H, Akiba S, Hatano H, *et al.* Asthma-like disease in the children living in the neighborhood of Mt. Sakurajima. *J Epidemiol* 1999; 9: 27–31.
- 7 Iwasawa S, Nakano M, Tsuboi T, *et al.* Effects of sulfur dioxide on the respiratory system of Miyakejima child residents 6 years after returning to the island. *Int Arch Occup Environ Health* 2015; 88: 1111–1118.
- 8 Tam E, Miike R, Labrenz S, *et al.* Volcanic air pollution over the Island of Hawai'i: emissions, dispersal, and composition. Association with respiratory symptoms and lung function in Hawai'i Island school children. *Environ Int* 2016; 92–93: 543–552.
- 9 Kraemer MJ, McCarthy MM. Childhood asthma hospitalization rates in Spokane County, Washington: impact of volcanic ash air pollution. *J Asthma* 1985; 22: 37–43.
- 10 Naumova EN, Yepes H, Griffiths JK, *et al.* Emergency room visits for respiratory conditions in children increased after Guagua Pichincha volcanic eruptions in April 2000 in Quito, Ecuador. *Environ Health* 2007; 6: 21.
- 11 Forbes L, Jarvis D, Potts J, *et al.* Volcanic ash and respiratory symptoms in children on the island of Montserrat, British West Indies. *Occup Environ Med* 2003; 60: 207–211.
- 12 Kimura K, Sakamoto T, Miyazaki M, *et al.* Effects of volcanic ash on ocular symptoms: results of a 10-year survey on schoolchildren. *Ophthalmology* 2005; 112: 478–481.
- 13 Hlodversdottir H, Thorsteinsdottir H, Thordardottir EB, *et al.* Long-term health of children following the Eyjafjallajökull volcanic eruption: a prospective cohort study. *Eur J Psychotraumatol* 2018; 9: 1442601.
- 14 Candal-Pedreira C, Díaz-Pérez D, Velasco V, *et al.* Lung function and symptoms of exposure to the volcanic eruption in the Canary Islands: first follow-up of the ASHES study. *Arch Bronconeumol* 2024; 60: 475–482.
- 15 Ruano-Ravina A, Acosta O, Díaz Pérez D, *et al.* A longitudinal and multidesign epidemiological study to analyze the effect of the volcanic eruption of Tajogaite Volcano (La Palma, Canary Islands). The ASHES study protocol. *Environ Res* 2023; 216: 114486.
- 16 Burney PG, Luczynska C, Chinn S, *et al.* The European Community Respiratory Health Survey. *Eur Respir J* 1994; 7: 954–960.
- 17 Stanojevic S, Kaminsky DA, Miller MR, *et al.* ERS/ATS technical standard on interpretive strategies for routine lung function tests. *Eur Respir J* 2022; 60: 2101499.
- 18 Dweik RA, Boggs PB, Erzurum SC, *et al.* An official ATS clinical practice guideline: interpretation of exhaled nitric oxide levels (F_{ENO}) for clinical applications. *Am J Respir Crit Care Med* 2011; 184: 602–615.
- 19 Bal C, Schiffers C, Breyer MK, *et al.* Fractional exhaled nitric oxide in a respiratory healthy general population through the lifespan. *Pulmonology* 2025; 31: 2442662.
- 20 Buist AS, Vollmer WM, Johnson LR, *et al.* A four-year prospective study of the respiratory effects of volcanic ash from Mt. St. Helens. *Am Rev Respir Dis* 1986; 133: 526–534.
- 21 Leus X, Quintanar C, Bowman V. Asthmatic bronchitis associated with a volcanic eruption in St. Vincent, west indies. *Disasters* 1981; 5: 67–69.
- 22 Buist AS, Bernstein RS, Johnson LR, *et al.* Evaluation of physical health effects due to volcanic hazards: human studies. *Am J Public Health* 1986; 76: 66–75.
- 23 Asher MI, Keil U, Anderson HR, *et al.* International Study of Asthma and Allergies in Childhood (ISAAC): rationale and methods. *Eur Respir J* 1995; 8: 483–491.
- 24 Kochi T, Iwasawa S, Nakano M, *et al.* Influence of sulfur dioxide on the respiratory system of Miyakejima adult residents 6 years after returning to the island. *J Occup Health* 2017; 59: 313–326.
- 25 Bateson TF, Schwartz J. Children's response to air pollutants. *J Toxicol Environ Health A* 2008; 71: 238–243.
- 26 Hahn Y-S. Measurements of fractional exhaled nitric oxide in paediatric asthma. *Korean J Pediatr* 2013; 56: 424–430.
- 27 Liu C, Flexeder C, Fuertes E, *et al.* Effects of air pollution on exhaled nitric oxide in children: results from the GINIplus and LISAPLUS studies. *Int J Hyg Environ Health* 2014; 217: 483–491.