

Effect of biomass smoke on chronic obstructive pulmonary disease in rural localities of Colombia

Efecto del humo de leña sobre enfermedad pulmonar obstructiva crónica en localidades rurales de Colombia

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ABSTRACT

Objectives The aim of this study was to assess the differences associated to the change of biofuel used to cook as a way to estimate the proportion of respiratory abnormalities of respiratory function associated to biomass exposure.

Methods A cross-sectional study was designed to evaluate the respiratory function through spirometry in subjects cooking with biomass or natural gas. All patients were evaluated by a general physician and a pulmonologist. We compared the prevalence of spirometry abnormalities across those cooking with natural gas versus those cooking with biofuel. A multivariable logistic regression and multiple linear regression were used to adjust differences by potential confounding factors.

Results 203 subjects were studied. There was a significant increase in the prevalence of severe obstructive pattern (OR 5.50; 95 % CI 1.17-25.79) in subjects who cook with biomass compared with natural gas users. Values of forced expired volume in one second (FEV₁) and forced vital capacity (FVC) were statistically lower among those cooking with biomass. The prevalence of respiratory morbidity and symptoms were not statistically significant between both groups.

Conclusions These findings suggest that replacing biomass fuel by natural gas may be an important public health intervention in Colombia, because it can reduce the prevalence of abnormal patterns of pulmonary function.

Key Words: Coal, respiratory tract diseases, chronic obstructive pulmonary disease (source: MeSH, NLM).

RESUMEN

Objetivos El objetivo de este estudio fue evaluar las diferencias asociadas al cambio de combustible usado para cocinar para gas natural como una manera de estimar la proporción de anomalías de la función respiratoria asociadas a exposición a biocombustibles.

Métodos Un estudio transversal fue diseñado para evaluar la función respiratoria en sujetos cocinando con biomasa o gas natural. Todos los pacientes fueron evaluados por un médico general y un neumólogo. Se comparó la prevalencia de anomalías respiratorias en aquellos sujetos cocinando con gas natural versus aquellos cocinando con biocombustibles. Una regresión lineal multivariable y una regresión logística fueron usadas para ajustar por potenciales factores de confusión.

Resultados 203 sujetos fueron estudiados. Se evidenció un incremento significativo en la prevalencia de patrón obstructivo severo en sujetos que cocinaron con biocombustibles comparados con aquellos que cocinaron con gas natural. Valores de Volumen espiratorio forzado (FEV_1) y capacidad vital forzada (FVC) fueron estadísticamente más bajos en los sujetos cocinando con biocombustibles. La prevalencia de morbilidad respiratoria percibida no fue estadísticamente diferente en los dos grupos.

Conclusiones Nuestros hallazgos sugieren que reemplazar biocombustibles por gas natural puede ser una intervención importante en salud pública en Colombia porque puede reducir la prevalencia de patrones anormales de función respiratoria.

Key Words: Carbón, enfermedades del tracto respiratorio; enfermedad pulmonar obstructiva crónica (*fuentes: DeCS, BIREME*).

Indoor air pollution continues to be an important cause of adverse health effects and mortality, especially in developing countries (1,2), where 50 % of residences and 90 % of rural houses use biofuels for cooking, the main cause of indoor air pollution (3). Recent estimations place the number of annual deaths associated to indoor air pollution between 1.5 and 2 million people, a million of those in children under 5 years old because of acute respiratory infections (1,4). According to estimations by Smith et. al., 24.6 % (95 % CI 18.8-30.8) of people in the Andean sub-region, where Colombia is located, (AMR-B) use biofuels for cooking (5). According to a meta-analysis by Po et. al. (2011) (6), Biofuel smoke is related to a 2.40 (95 % CI 1.47-3.93) increase of chronic obstructive pulmonary disease (COPD) and 2.52 (95 % CI 1.88-3.38) increase of chronic bronchitis in women.

When biofuels are used in stoves of inefficient combustion they generate high concentration of contaminants. Respirable particulate matter (PM) with diameters $<10 \mu\text{m}$ (PM_{10}) have concentrations from PM_{10} 300 to $3000 \mu\text{g}/\text{m}^3$ for a 24 h period; and indoor CO levels from 1.2 to 43

ppm (7). Recommended standards in USA according to the United States Environmental Protection Agency are $PM_{10} < 150 \mu\text{g}/\text{m}^3$ (8), and $CO < 5$ ppm in indoor settings (7). Wood burning stoves and fireplaces contain significant levels of carbon monoxide (CO), nitrogen and sulfur oxides, aldehydes, and PM_{10} y $PM_{2.5}$, all of them with a demonstrated adverse effect on human health (7).

The burden of disease associated to solid biofuels is notorious in communities with inadequate access to clean fuels, particularly poor homes in rural areas of developing countries, where it is estimated that constitute a 2.7 % of overall health risks (1,9). A dose-response relation have been found between exposition to smoke from biomass, particularly wood smoke, and acute respiratory infections, chronic obstructive pulmonary disease COPD, lung cancer, asthma, tuberculosis and low birth weight (1,10-17).

The aim of the present study was to contribute to increase the scientific evidence on biofuels and adverse respiratory effects in Latin America, where these data are scarce. This study assessed clinical and laboratory parameters that have not been measured previously in other studies in the region.

METHODS AND MATERIALS

This is a cross-sectional study that evaluated the respiratory function on a convenient sample of two populations. One sample cooks with biomass (wood, charcoal, organic waste), and another sample cooks with natural gas. Respiratory function was assessed through clinical and spirometry evaluation. The two rural localities were Santa Ana (0 meters above sea) and San Pablo (75 meters above sea), from the Caribbean region of Colombia.

Population

The sample was taken from the two localities, one group of subjects using fuel and the other one cooking with biofuels. The survey was carried out during 2008 in patients older than 30 years old.

Identification and ascertainment of participants

An open call of voluntary participants was made in the chosen localities. Each subject and the locality leaders were informed of the aims of the study, and each subject before inclusion they were asked to give their informed consent. Because no invasive techniques were used, it was estimated that this study posed low risks for participants. No patient refused the test.

Overall 203 adults were included in the sample. A pulmonologist (JMF) and a trained physical therapist performed the spirometry.

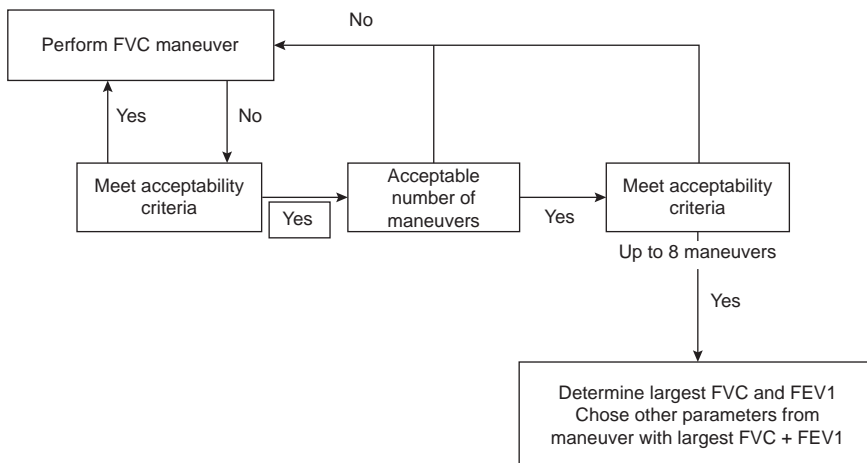
Studied variables

A 26 item questionnaire was filled by a general practitioner to gather clinical characteristics, and after obtaining a verbal consent, a spirometry was performed by a medical doctor trained in neumology. The questionnaire collected variables on perceived morbidity, respiratory symptoms (cough, expectoration, dyspnea), previously diagnosed respiratory disease (asthma, chronic obstructive pulmonary disease), demographic and socio-economic background (age, sex, type of health care provider, education, weight and height), self-reported smoking status, and spirometry results.

Exposure

As mentioned before, we included two populations in the study, one cooking with natural gas and the other one with biomass. We considered as exposed those cooking with biomass >1 time per week during the last year. Information on exposure was assessed using a questionnaire. Those currently cooking with natural gas were considered unexposed.

Figure 1. Flow-chart diagram of FVC spirometry testing.



Spirometry procedure

Participants were explained about the research scope, and they were asked to undertake a spirometry test. Before performing the spirometry data was collected on presence of respiratory symptoms and smoking history.

Participants had a medical checkup by a physician before the spirometry procedure was undertaken.

A portable spirometer (BURDICK®) was installed in the community center of each locality and all tests were performed in those facilities. The spirometer recorded age in years (E), height in centimeters (T) and weight in kilograms (P) to estimate FVC through the next equations:

$$\text{Male} = 0.028 T + 0.0345 P + 0.0573 E - 3.21$$

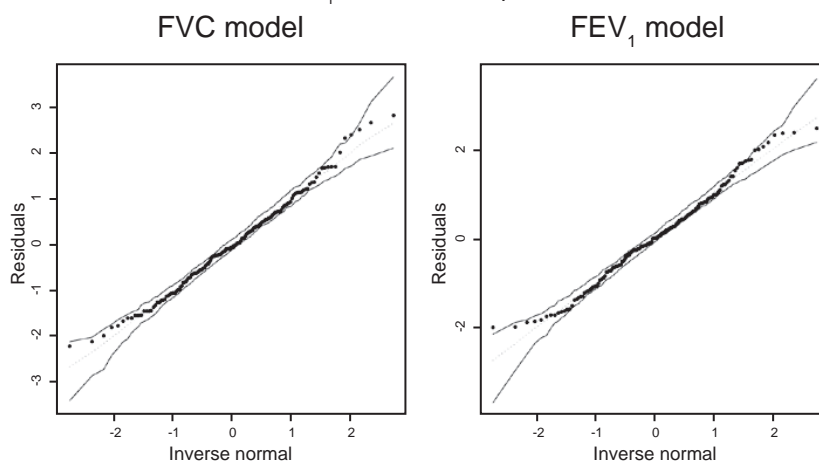
$$\text{Female} = 0.0305 T + 0.0222 P + 0.0356 E - 3.04$$

The method to perform the spirometry is explained in Figure 1.

Interpretation

Qualitative patterns to interpret are: a. Normal pattern; b. Obstructive pattern; c. Restrictive pattern, and; d. Mixed pattern; evaluating the severity of each one (mild, moderate and severe). The interpretation was made by a pulmonologist.

Figure 2. Q-Q plot for normality of residuals of the multiple linear regression models with FEV_1 and FVC as dependent variables.



Statistical analysis: After data was collected, it was analyzed using the statistical software Stata (Stata for Windows 11.1; Stata Corp; Texas, US). Body mass index (BMI), FEV_1 and FVC were expressed in mean with standard deviation ($SD \pm$). Age, BMI, and education were categorized and reported with percentages. The risk of having a different spirometry

pattern than normal was compared between those cooking with natural gas or biomass. A multiple linear regression β coefficient was estimated to assess the linear relationship between Forced expiratory volume in 1 second (FEV_1) and Forced vital capacity (FVC) with the exposure variable, adjusted by age above 65, BMI, smoking, passive smoking and previous respiratory disease. Confidence intervals of 95 % and R2 were estimated. The following tests were used to test model adequacy: Studentized Breusch-Pagan test for homoscedasticity of residuals (not significant for both models), Q-Q plot for normality of residuals (Figure 2), and tests for multicollinearity. Multivariable logistic regression was used to adjust by age, sex, education, BMI and smoking. Confidence intervals of 95 % were used to determine Odds Ratio (OR). Categorical data was compared using chi-square (A P-value < 0.05 was considered significant).

RESULTS

Table 1. Characteristics and differences between population Cooking with natural gas or biofuel

	Fuel used for cooking		Total n (%)	p^*
	Natural Gas n (%)	Biofuels n (%)		
Smoking	33 (28.9)	13 (24.1)	46 (27.4)	0.581
Age				0.280
30-49	55 (48.2)	19 (35.1)	74 (44.5)	
50-69	41 (35.9)	24 (44.4)	65 (38.6)	
≥ 70	18 (15.7)	11 (20.3)	29 (17.2)	
Gender				0.402
Female	84 (73.7)	43 (79.6)	127 (75.6)	
BMI				0.319
BMI <18.5	51 (13.1)	12 (22.2)	27 (16.0)	
BMI 18.5-29.9	76 (66.6)	33 (61.1)	109 (64.8)	
BMI ≥ 30	23 (20.1)	9 (16.6)	32 (19.5)	
Education				0.003
No Education	18 (15.9)	19 (35.1)	37 (22.1)	
Complete Elementary	64 (56.6)	30 (55.5)	94 (56.2)	
High School and University Education	31 (27.4)	5 (9.26)	36 (21.5)	
Health Care Provider				0.660
No Health Care Provider	14 (12.5)	5 (9.4)	19 (11.5)	
Sponsored †	91 (81.3)	46 (86.8)	137 (83)	
Contributive ‡	7 (6.3)	2 (3.8)	9 (5.5)	

* $p < 0.05$ was considered significant. BMI: Body Mass Index; † In Colombian Health Care System the Sponsored plan is paid by the government; ‡ In Colombian Health Care System the Contributive plan is paid by the person, and it covers more health care procedures and drugs than the sponsored plan.

General characteristics

A total of 203 subjects were surveyed, 87 (42.9 %) in San Pablo and 116 (57.1 %) in Santa Ana. There were 35 subjects excluded from analysis because neither, fuel nor age, could be determined. Age was not reported from 26 participants and 11 did not report combustible type. No participant was excluded because of poor spirometry.

Gender, age group, and fuel type were not significantly different between patients with and without restrictive spirometry patterns (Table 2).

Table 2. Gender, age and fuel type by obstructive and restrictive spirometry pattern

	Obstructive Pattern		ρ^*	Restrictive Pattern		ρ^*
	Present	Not Present		Present	Not Present	
Gender						
Female	50 (73.5)	77 (77)	0.607	26 (78.7)	101 (74.8)	0.634
Age			0.030			0.586
30-49	22 (32.3)	52 (52)		12 (36.3)	62 (45.9)	
50-69	30 (44.1)	35 (35)		14 (42.4)	51 (37.7)	
≥ 70	16 (23.5)	13 (13)		7 (21.2)	22 (16.3)	
Fuel type			0.163			0.504
Natural Gas	42 (61.7)	72 (72)		24 (72.7)	90 (66.6)	
Biofuels	26 (38.2)	28 (28)		9 (27.2)	45 (33.3)	

* $\rho < 0.05$ was considered significant.

Comparisons of BMI through ANOVA between people cooking with natural gas (mean: 25.2, SD 6) and people cooking with biofuel (mean: 23.9, SD 6.4) were not significant ($P=0.197$). FEV_1 was significantly different between the natural gas and the biofuel group (mean: 2.3, SD 0.7; versus 2.0, SD 0.7, respectively) ($P=0.011$). The FVC was also significantly different between the natural gas and the biofuel group (mean: 2.7, SD 0.8; versus 2.3, SD 0.8, respectively) ($P=0.013$). In both the FEV_1 and the FVC the people cooking with natural gas had better spirometry parameters.

Multivariable analyses

Multivariable logistic regression results show a significant increase of the risk to present respiratory alterations of the severe obstructive pattern in the population cooking with biofuels (OR 5.50; 95 % CI 1.17 to 25.79). Others risk assessments were not significant, including estimations of morbidity and respiratory symptoms (cough, expectoration and dyspnea).

Multiple linear regression showed a significant decrease of the estimator coefficient of FEV_1 in people using biofuels (-0.22; 95 % CI -0.43 to

-0.02), and a significant decrease of the estimator coefficient of FVC in people using biofuels (-0.25;95 % CI -0.47 to -0.02). The two models were stratified by gender (Table 4). The Breusch-Pagan test was not significant for all models. Q-Q plot for normality of residuals of models with all subjects can be seen in Figure 2.

Table 3. Estimation of the effects of biofuels cooking on spirometry patterns and respiratory diseases with logistic regression

	Crude OR (95 % CI)	Adjusted OR (95 % CI)*
Normal Pattern	0.68 (0.34-1.35)	0.86 (0.41-1.81)
Obstructive Pattern	1.59 (0.82-3.06)	1.39 (0.69-2.82)
Mild	0.66 (0.26-1.66)	0.59 (0.22-1.55)
Moderate	1.50 (0.62-3.60)	2.25 (0.54-9.42)
Severe	3.60 (1.21-10.70)	5.50 (1.17-25.79)**
Restrictive Pattern	0.75 (0.32-1.74)	0.64 (0.26-1.55)
Mild	0.42 (0.13-1.32)	0.39 (0.12-1.27)
Moderate	2.80 (0.72-10.90)	2.25 (0.54-9.41)
Severe	N.E.	N.E.
Respiratory Disease	0.62 (0.20-1.65)	0.56 (0.21-1.45)
Asthma	0.45 (0.16-1.27)	0.42 (0.14-1.23)
COPD	4.34 (0.38-49.01)	3.93 (0.33-46.7)
Cough	1.09 (0.56-2.11)	1.07 (0.53-2.12)
Expectoration	0.81 (0.41-1.63)	0.82 (0.39-1.70)
Dyspnea	1.06 (0.55-2.03)	1.05 (0.53-2.09)

N.E.: Not Estimable; * Adjusted by age, sex, education, BMI, and smoking; ** P-value <0.05

Table 4. Estimation of the effects of biofuels cooking on spirometry patterns and respiratory diseases with multiple linear regression

	β (95 % Confidence Interval)	p-value	Adjusted-R ²
FEV ₁			
All subjects	-0.22 (-0.43 to -0.02)	0.026	0.35
Women (n=127)	-1.60 (-0.35 to 0.02)	0.097	0.42
Men (n=41)	0.00 (-0.50 to 0.52)	0.971	0.42
FVC			
All subjects	-0.25 (-0.47 to -0.02)	0.027	0.34
Women (n=127)	-0.21 (-0.42 to -0.00)	0.045	0.41
Men (n=41)	0.08 (-0.44 to 0.61)	0.740	0.46

DISCUSSION

The present study adds on to the evidence of the association between indoor air pollution and reduction of several pulmonary function indicators. This is important because there are sparse data on indoor air pollution and deleterious respiratory effects for Latin America and the Caribbean using

specific measures such as spirometry. The study shows a significant risk of a reduction of pulmonary function among those cooking with biomass or biofuels, when compared to people who used to cook with biomass but had shifted within the last 3 years to cooking with natural gas. The magnitude of the association was quite strong since people cooking with biofuels had a 5 times higher risk of having a severe obstructive pattern in the spirometry test.

This is one of the few population based studies on assessing the effects of indoor air pollution on population health in Latin America, which has the additional strength of having used spirometry to assess the respiratory function. A report from the World Health Organization (2002) found that 21 studies has assessed the association between indoor air pollution and Chronic Obstructive Pulmonary Disease (COPD) (18) between 1959 and 1999. Only 12 of them use spirometry to evaluate COPD, just four were carried out in Latin America and only two were community-based. The study made by Regalado in Mexican's women (2006) (19) was similar in methodology to the study presented here, but despite the large sample of people cooking with biomass (778 subjects), they did not find a significant relationship between lower FEV₁ and FVC with biomass smoke. They did found however, a greater prevalence of PM₁₀, and respiratory symptoms in subjects who cooked with biomass. We did not found the later effect, which can be explained for the subjectivity of perceived symptom.

Albalak et. al. in Bolivia (2009) (20) assessed the exposure with PM₁₀ measurements, but no spirometry data was collected. They did found an adjusted OR of 0.4 for chronic bronchitis in subjects cooking outdoors, compared with subjects cooking indoors.

Many studies relate wood smoke from biomass with respiratory diseases (13,15,19,21), and there is enough evidence of the direct effects of the components of wood smoke on the lung (22) to estimate the burden of disease of biomass smoke (2,4). Ezzati y Kammen (2001) performed an exposure-response study that proved exposure to indoor PM₁₀ increases the frequency of acute respiratory infections in the setting of a low income country (Kenya) (13). It has been suggested that PM₁₀ increases the risk of COPD (15), a studies in developing countries support this conclusion (23,24). A recent meta-analysis suggests that biomass smoke is associated with an increase in the risk of COPD (25), but included studies in the meta-analysis may have suffered from recall bias, according to the authors.

Despite of that, it is unknown the level of pulmonary involvement, or what physiologic respiratory patterns are affected by smoke components. The evidence result of this study put FEV₁ and FVC at the center of the alteration of the respiratory pattern caused by biomass smoke, and motivate the design and implementation of new individual-level studies in this subject.

This study has limitations. One limitation was the limited sample size, which lowered power and prevented better comparisons, especially in the risk assessment. Another limitation is related to the study design; as a cross-sectional study, the timeline of exposure-disease is not well established. Other important limitation was the incomplete determination of exposure to biomass smoke. Most of the population was exposed to biomass smoke for their lifetimes, because natural gas arrived to localities less than four years ago. This represents a bias, because the true level of clinical involvement already establish at the long term cannot be determined. This effectively underestimates the results because many people with the exposure before the four years may have had already lung damage and were categorized as natural gas.

Table 1 describe the population characteristics, and finds no differences of age, gender, BMI, and type of health care provider between the two studied groups. These results are correlated with the relation biofuel cooking-poverty, shown in the high prevalence of biofuel cooking in countries with low Gross Domestic Product (26). Besides, the lack of differences between the two studied groups and the multivariable analyses mitigate the selection bias resulted from the convenience simple.

In conclusion, this study increases evidence on the harmful effect of biofuels smoke in human health, and particularly in Colombia, recommends the assessment of potential health and/or economic benefits of introducing natural gas on rural populations of Colombia ♦

Authors' contributions: NA and FD developed the protocol and analyzed the data. JM reviewed the paper and performed the spirometry. AP drafted the manuscript and helped analyzed the data.

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REFERENCES

1. Bruce N, Perez-Padilla R, Albalak R. Indoor air pollution in developing countries: a major environmental and public health challenge. *Bull World Health Organ.* 2000;78(9):1078-92.
2. Smith KR, Mehta S. The burden of disease from indoor air pollution in developing countries: comparison of estimates. *Int J Hyg Environ Health.* 2003 Aug;206(4-5):279-89.
3. World Resources Institute. *World Resources 1998-99: Environmental change and human health.* World Bank, editor. Oxford: : Oxford University Press; 1998.
4. Hong C. *Global burden of disease from air pollution.* WHO, editor. Geneva: Switzerland; 1995.
5. Smith KR, Samet JM, Romieu I, Bruce N. Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax.* 2000 Jun;55 (6):518-32.
6. Po JY, FitzGerald JM, Carlsten C. Respiratory disease associated with solid biomass fuel exposure in rural women and children: systematic review and meta-analysis. *Thorax.* [Meta-Analysis Research Support, Non-U.S. Gov't Review]. 2011 Mar;66(3):232-9.
7. Zelikoff JT, Chen LC, Cohen MD, Schlesinger RB. The toxicology of inhaled woodsmoke. *J Toxicol Environ Health B Crit Rev.* 2002 Jul-Sep;5(3):269-82.
8. EPA. National Ambient Air Quality Standards (NAAQS). 2010. [Internet]. Available from: <http://www.epa.gov/air/criteria.html>.
9. Alvis N, De la Hoz F. Contaminación del aire domiciliario y enfermedades respiratorias (Infección Respiratoria Aguda Baja, EPOC, Cáncer de Pulmón y Asma): evidencias de asociación. *Rev Fac Med Unal.* 2008;56 (1):54-64.
10. Hakim AK, Kharboush IF, Naguib KK, Mortada MM, Noweir KH, El A, II. Indoor air pollution and acute lower respiratory infections in the first two years of life. *J Egypt Public Health Assoc.* 1995;70 (5-6):661-78.
11. Campbell H. Indoor air pollution and acute lower respiratory infections in young Gambian children. *Health Bull (Edinb).* 1997 Jan;55 (1):20-31.
12. Smith KR. Indoor air pollution and acute respiratory infections. *Indian Pediatr.* 2003 Sep;40(9):815-9.
13. Ezzati M, Kammen D. Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. *Lancet.* 2001 Aug 25;358 (9282):619-24.
14. Diaz E, Bruce N, Pope D, Lie RT, Diaz A, Arana B, et al. Lung function and symptoms among indigenous Mayan women exposed to high levels of indoor air pollution. *Int J Tuberc Lung Dis.* 2007 Dec;11(12):1372-9.
15. Liu Y, Lee K, Perez-Padilla R, Hudson NL, Mannino DM. Outdoor and indoor air pollution and COPD-related diseases in high- and low-income countries. *Int J Tuberc Lung Dis.* 2008 Feb;12 (2):115-27.
16. Ezzati M, Kammen DM. Quantifying the effects of exposure to indoor air pollution from biomass combustion on acute respiratory infections in developing countries. *Environ Health Perspect.* 2001 May;109 (5):481-8.
17. Boy E, Bruce N, Delgado H. Birth weight and exposure to kitchen wood smoke during pregnancy in rural Guatemala. *Environ Health Perspect.* 2002 Jan;110 (1):109-14.

18. Bruce N, Perez-Padilla R, Albalak R. The health effects of indoor air pollution exposure in developing countries. Geneva, Switzerland: World Health Organization; 2002.
19. Regalado J, Perez-Padilla R, Sansores R, Paramo Ramirez JI, Brauer M, Pare P, et al. The effect of biomass burning on respiratory symptoms and lung function in rural Mexican women. *Am J Respir Crit Care Med*. 2006. Oct 15;174 (8):901-5.
20. Albalak R, Frisancho AR, Keeler GJ. Domestic biomass fuel combustion and chronic bronchitis in two rural Bolivian villages. *Thorax*. 1999 Nov;54(11):1004-8.
21. Dennis RJ, Maldonado D, Norman S, Baena E, Martinez G. Woodsmoke exposure and risk for obstructive airways disease among women. *Chest*. 1996 Jan;109 (1):115-9.
22. Sandoval J, Salas J, Martinez-Guerra ML, Gomez A, Martinez C, Portales A, et al. Pulmonary arterial hypertension and cor pulmonale associated with chronic domestic woodsmoke inhalation. *Chest*. 1993 Jan;103 (1):12-20.
23. Golshan M, Faghihi M, Marandi MM. Indoor women jobs and pulmonary risks in rural areas of Isfahan, Iran, 2000. *Respir Med*. 2002 Jun;96(6):382-8.
24. Kiraz K, Kart L, Demir R, Oymak S, Gulmez I, Unalacak M, et al. Chronic pulmonary disease in rural women exposed to biomass fumes. *Clin Invest Med*. 2003 Oct;26 (5):243-8.
25. Hu G, Zhou Y, Tian J, Yao W, Li J, Li B, et al. Risk of COPD from exposure to biomass smoke: a metaanalysis. *Chest*. 2010 Jul;138 (1):20-31.
26. Smith K, Apte MY, M., Wongsekiarttirat W, Kulkarni A. Air Pollution and the Energy Ladder in Asian Cities. *Energy*. 1994;19 (5):587-600.