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Influence of the lab based simulation of truck shipments on the level of carbon dioxide in carbonated soft drinks packed in PET bottles

Influência de simulação de transporte rodoviário em laboratório no nível de dióxido de carbono em refrigerantes acondicionados em garrafas PET

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Summary

Truck shipment is the main means of transportation for the majority of the agricultural and industrial production in Latin America, where road conditions are very precarious. Mexico and Brazil, two countries with considerable areas and populations, occupy the 2nd and 3rd places, respectively, in the worldwide ranking of Carbonated Soft Drinks (CSD) consumption, which are mainly packed in PET bottles capped with plastic closures. In this packaging system, the CSD shelf-life is defined by the loss of carbon dioxide (CO_2), which takes place mainly as this gas permeates through the bottle and the closure system during storage and distribution. The objective of this study was to evaluate the truck shipment effect on carbon dioxide loss from carbonated soft drinks using lab based simulation. PET bottles of different flavoured CSD were submitted to a truck vibration lab testing, and the volume of carbon dioxide dissolved in the beverage and the bottle's main dimensions assessed before (zero time), and after 1, 2 and 3 h of vibration testing, and also 48 h after the end of the vibration test. Sampling was carried out such that it was also possible to evaluate the influence of the bottle's position in the pallet. The results showed that truck shipment greater than 1,500 miles (2,400 km) and the bottle's stacking position (4 layers) had little affect on the CO_2 level in CSD packed in 2 L PET bottles or larger ones. In addition, the vibration testing time and the bottle's position in the pallet did not significantly affect the bottle's dimensions.

Key words: *Truck shipment; Carbonation loss; Carbonated soft drink; PET bottle.*

Resumo

O transporte rodoviário é o principal meio de transporte da maior parte da produção agrícola e industrial na América Latina, onde as condições das estradas são muito precárias. México e Brasil, dois países com área e população consideráveis, ocupam a 2ª e a 3ª posições, respectivamente, no consumo mundial de bebidas carbonatadas, em grande parte embaladas em garrafas de PET com tampas plásticas. Neste sistema de embalagem, a vida-de-prateleira das bebidas carbonatadas é definida pela perda de gás carbônico (CO_2), que ocorre principalmente com a permeação deste gás através das paredes da garrafa e do sistema de fechamento durante a estocagem e a distribuição. O objetivo deste estudo foi avaliar o efeito do transporte rodoviário, através de simulação em laboratório, sobre a perda de carbonatação em refrigerantes. Garrafas de PET contendo refrigerantes de diferentes sabores foram submetidas a ensaios de vibração, com perfil rodoviário, nos quais o volume de gás carbônico dissolvido na bebida, bem como as principais dimensões da garrafa, foram determinados antes do início da vibração, 1, 2 e 3 h após o ensaio de vibração, e também 48 h após o término do ensaio. A amostragem foi efetuada de maneira a possibilitar a avaliação da influência do posicionamento da garrafa no empilhamento. Os resultados mostraram que o transporte rodoviário acima de 1.500 milhas (2.400 km) e a posição das garrafas no empilhamento utilizado (quatro camadas) não afetaram consideravelmente o nível de CO_2 nas bebidas acondicionadas em garrafas de PET de 2 L. Além disso, o tempo de ensaio de vibração e a posição da garrafa no empilhamento não afetaram significativamente as dimensões da garrafa.

Palavras-chave: *Transporte rodoviário; Perda de carbonatação; Bebida carbonatada; Garrafa de PET.*

1 Introduction

Brazil is the third world market for soft drinks with a total consumption of 13 billion litres in 2006, following the United States and Mexico (FIPE, 2009). The Brazilian market, with 11.5 million litres in 2000, grew about 22% up to 2007. The determinant factors for growth were the increase in purchasing power and the use of disposable (one-way) bottles, which completely transformed the distribution logistics, extending its action limits (ACIRRAM-SE, 1999; DATAMARK, 2009).

The loss in quality and reduction in shelf-life of carbonated soft drinks are due mainly to a loss of carbon dioxide through the bottle, which results in flavour changes. The loss in CO_2 can reduce the package compression strength, which can result in damage during shipment.

Gas losses take place by permeation through the plastic bottle walls and by permeation or leakage through the closure system. Such gas losses from PET bottles are associated with the bottle weight, material distribution, bi-orientation level of the polymer chains, plastic cap characteristics and integrity of the closure system. Garcia et al. (1989) summarized the permeation process in a didactic way as consisting of three phases: (1) permeant absorption and dissolution on the polymer surface, (2) permeant diffusion through the material due to a concentration gradient action, and finally (3) permeant dessorption and evaporation on the other polymer surface.

In carbonated beverages there is a carbon dioxide loss during product storage. This aspect is of great concern to the manufacturer and has been widely studied since the introduction of PET bottles on to the market. It was also taken into account when companies were forced to reduce the bottle weight due to environmental and economic pressure. Nobile et al. (1997) proved, using mathematical modelling, the importance of considering the effect of environmental temperature fluctuations on the shelf-life of carbonated soft drinks.

However, the vibration effect during truck shipment and distribution from bottling to retail has not been well studied, and the real influence of this stage on product shelf-life has yet to be defined. In order to reduce such problems and assure that the consumer receives the product with the same quality as immediately after production, some companies are working on optimizing the distribution process of their products, by controlling the fleet quality, truck type, chassis type and load handling (MARTINO, 1999).

In Brazil, the distribution chain may be over 3,000 km. For this study, the correlation between the real transportation distance and the test time was based on the ISTA 3E procedure – Unitized Loads of Same Product (ISTA, 2008). In this procedure, for transport distances over 2,400 km, a 3 h vibration test is recommended. Although the vibration profile suggested in the ISTA 3E differed slightly from the profile used in the present study, this correlation was considered.

Sarantópoulos et al. (2003) studied the transportation effect up to 3,000 km on the carbon dioxide level in guaraná (Brazilian fruit beverage) and lemon flavoured CSD, packed in 2 L PET bottles with different weights and capped with closures with and without liners. The results showed that the shipment and distribution caused a significant loss in carbon dioxide level in 3 of the 6 samples analyzed. However, 48 h later, the CO_2 loss was still significant in only 2 of these 3 samples.

Considering that the effect of truck shipment on the loss of CO_2 in carbonated drinks packed in PET bottles has not been established, the present work aimed to find further information about the effect of transportation time and position in the load unit (stacking layer) on the carbonation level in CSD packed in PET bottles, during this important phase in the distribution cycle of beverages, using truck transportation lab test simulation.

2 Material and methods

PET bottles capped with plastic closures with liners and filled with guaraná and cola flavoured soft drinks, were studied.

In the first phase, a sample identified as Guaraná 1 (straight walled bottle weighing 53 g with a capacity for 2 L) was analyzed. This sample underwent a shipment vibration test and the carbonation level, total height and diameter of the CSD bottles were assessed at periodic intervals.

In the second phase, three samples were analyzed, identified as Guaraná 2 (straight walled bottle weighing 57 g with a capacity for 2 L), *Cola* 1 (contour bottle weighing 66 g with a capacity for 2.5 L) and *Cola* 2 (contour bottle weighing 54 g with a capacity for 2 L). These samples underwent a shipment vibration lab test and the CO_2 level dissolved in the beverage was assessed at periodic intervals immediately after vibration.

All the results were analysed statistically using the Tukey test at a 95% confidence level.

2.1 Shipment vibration lab testing

The shipment vibration lab test was carried out according to the ASTM standard D 4728-06 (2006), using the power spectrum density suggested for trucks (Figure 1), root mean square (rms) of 0.52 G during 3 h, with interruptions after 1 and 2 h for sampling.

The test was carried out on a 1.5 x 1.5 m MTS model 495.10 vibration table, with 5 t of dynamic force in vibrations controlled by an MTS model "407 Controller" and a Data Physics "SignalCalc 550 Vibration Controller".

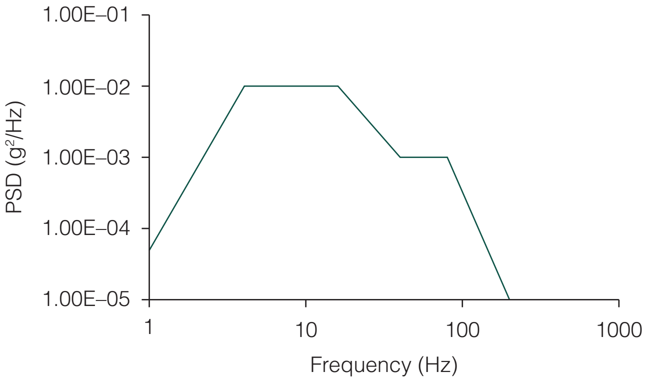

Figure 1. Power Spectrum Density (PSD) suggested for trucks (ASTM, 2006).[9]

Multipacks with 6 bottles wrapped by shrink polyethylene film were put on the vibration table in a column order with 4 multipacks in height, layer 1 being the one in contact with the vibration table. The layers were separated by plywood partitions. The side movement of the multipacks was horizontally restricted by the equipment columns. All the bottles submitted to shipment vibration lab testing were previously conditioned at 23 ± 1 °C for about 48 h, and the test was also carried out in an environment at 23 ± 1 °C.

2.2 Dimensional assessment

The total height and diameter of the bottles were determined before the shipment vibration test, after 1, 2 and 3 h of vibration testing and 48 h after the vibration test, in order to assess possible dimensional changes of the bottle due to pressure changes, which could influence the carbonation level. Six units of Guaraná 1 sample were assessed in each period.

The total height was determined by a Mitutoyo height meter with a resolution of 0.01 mm, based on the ASTM D 2911-94 (2005).

The body diameter was measured on the bottle-labelling panel at a height of 153.5 mm from the bottom, using a Mitutoyo diameter meter with a resolution of 0.01 mm, also according to ASTM D 2911-94 (2005).

2.3 Carbonation level

The beverage carbonation level was determined in 6 units just before the shipment vibration test, and in 6 units from each load unit layer after 1, 2 and 3 h of vibration testing. It was also determined 48 h after the end of the shipment vibration testing. Methodology based on the ASTM F 1115-95 (2008) procedure B (Zahm-Nagel system with a manometer in the range from 0 to 100 lbf/in^2 and a resolution of 0.5 lbf/in^2) was used. The bottles were shaken immediately before measurement. The CO_2 volume dissolved in the water volume was obtained using the carbonation volume table presented in ASTM F 1115-95 (2008).

3 Results and discussion

3.1 Dimensional assessment

For the Guaraná 1 sample, the bottle position (layer) in the load unit had no significant influence on its total height during and 48 h after the end of the shipment vibration test. With respect to the vibration testing time, a significant reduction (at the 5% level) in the total bottle height was found in layer 4 (on top) after 1 and 2 h of vibration testing and 48 h after it ended, as compared to a non-vibrated test bottle. The reduction was 0.5 mm (0.1%), which can be considered irrelevant, since it is within the admitted deviation for the total bottle height, which is usually greater than 1.0 mm.

With respect to the Guaraná 1 bottle diameter (Table 1), a significant effect of the position of the bottle in the load unit was verified after 3 h of vibration testing between the bottles in layers 2 and 4. The shipment vibration test resulted in a significant difference in bottle diameter in the bottles placed in layers 2 and 3. In layer 3, an increase in the diameter was registered after one hour of vibration testing, but it subsequently returned to its initial condition. In layer 2 there was a reduction in the diameter after between 2 and 3 h of vibration testing, which also subsequently returned to its initial condition. The greatest mean difference was 1 mm, which is practically irrelevant. Forty-eight h after the end of the shipment vibration test, no significant effect of the shipment time or the bottle position in the load was detected, even in its diameter.

Thus eventual changes in the carbonation volume are not associated with dimensional changes resulting from internal pressure variation.

Since irrelevant dimensional variations were found, as reported in preliminary studied (SARANTÓPOULOS et al., 2003) the dimensional parameters were not assessed for the other three samples studied.

3.2 Carbonation level

Tables 2 to 5 show the results for carbonation level. The shipment vibration lab testing time and subsequent storage did not result in significant changes in the carbonation level of Guaraná 1 (Table 2), Cola 1 (Table 3) or Cola 2 (Table 5) samples.

For Guaraná 1 (Table 2), the bottle position in the load unit showed a significant influence after 1 h of shipment vibration testing, but it was not consistent. The high standard deviation in carbonation volume amongst the units assessed in Guaraná 1 may reflect considerable instability in the filling line with respect to carbonation.

For the Cola 1 (Table 3) samples, the product carbonation level was not significantly influenced by the bottle position in the load unit for any of the situations

Table 1. Guaraná 1 - bottle diameter.

Vibration testing	Diameter (mm)				
	Layer 1 (on bottom)	Layer 2	Layer 3	Layer 4 (on top)	m.s.d (5%)
Without	100.5 ± 0.42^{aA}	100.5 ± 0.42^{abcA}	100.5 ± 0.42^{bA}	100.5 ± 0.42^{aA}	0.00
1 h	100.8 ± 0.35^{aA}	101.0 ± 0.31^{abA}	101.4 ± 0.39^{aA}	101.0 ± 0.46^{aA}	0.62
2 h	100.7 ± 0.57^{aA}	101.2 ± 0.65^{aA}	100.6 ± 0.31^{bA}	101.5 ± 0.71^{aA}	0.94
3 h	100.5 ± 0.18^{aAB}	100.4 ± 0.31^{bcB}	100.6 ± 0.53^{bAB}	101.0 ± 0.48^{aA}	0.64
3 + 48 h at 23 °C	100.3 ± 0.73^{aA}	100.2 ± 0.47^{cA}	100.9 ± 0.47^{abA}	100.5 ± 0.65^{aA}	0.96
m.s.d. (5%)	0.82	0.76	0.73	0.94	-

^{a,b,c}Means in the same column followed by the same small letter do not significantly differ from each other by the Tukey test at a 5% error rate, with respect to the shipment vibration testing time; ^{A,B}means in the same line followed by the same capital letter do not significantly differ from each other by the Tukey test at a 5% error rate, with respect to the bottle position (layer) in the pallet; m.s.d: minimum significant difference.

Table 2. Guaraná 1 - carbonation volumes.

Vibration testing	Carbonation volume (v/v)				
	Layer 1 (on bottom)	Layer 2	Layer 3	Layer 4 (on top)	m.s.d. (5%)
Without	3.16 ± 0.14^{aA}	3.16 ± 0.14^{aA}	3.16 ± 0.14^{aA}	3.16 ± 0.15^{aA}	0.22
1 h	3.09 ± 0.06^{aB}	3.15 ± 0.09^{aAB}	3.12 ± 0.06^{aAB}	3.22 ± 0.10^{aA}	0.13
2 h	3.13 ± 0.09^{aA}	3.12 ± 0.09^{aA}	3.16 ± 0.13^{aA}	3.13 ± 0.07^{aA}	0.16
3 h	3.07 ± 0.04^{aA}	3.16 ± 0.14^{aA}	3.08 ± 0.16^{aA}	3.15 ± 0.13^{aA}	0.20
3 + 48 h at 23 °C	3.14 ± 0.06^{aA}	3.16 ± 0.09^{aA}	3.12 ± 0.11^{aA}	3.15 ± 0.12^{aA}	0.16
m.s.d. (5%)	0.19	0.19	0.21	0.19	-

^{a}Means in the same column, followed by the same small letter, do not significantly differ from each other by the Tukey test at a 5% error rate with respect to the shipment vibration testing time; ^{A,B}means in the same line followed by the same capital letter do not significantly differ from each other by the Tukey test at a 5% error rate with respect to the bottle position (layer) in the pallet; m.s.d.: minimum significant difference.

Table 3. Cola 1 - carbonation volume.

Vibration testing	Carbonation volume (v/v)				
	Layer 1 (on bottom)	Layer 2	Layer 3	Layer 4 (on top)	m.s.d. (5%)
Without	3.68 ± 0.06^{aA}	3.68 ± 0.06^{aA}	3.68 ± 0.06^{aA}	3.68 ± 0.06^{aA}	0.09
1 h	3.70 ± 0.03^{aA}	3.75 ± 0.05^{aA}	3.73 ± 0.04^{aA}	3.72 ± 0.05^{aA}	0.08
2 h	3.70 ± 0.03^{aA}	3.70 ± 0.06^{aA}	3.53 ± 0.44^{aA}	3.64 ± 0.04^{aA}	0.36
3 h	3.70 ± 0.03^{aA}	3.65 ± 0.06^{aA}	3.60 ± 0.26^{aA}	3.70 ± 0.06^{aA}	0.23
3 + 48 h at 23 °C	3.64 ± 0.03^{aA}	3.43 ± 0.55^{aA}	3.72 ± 0.05^{aA}	3.71 ± 0.04^{aA}	0.44
m.s.d. (5%)	0.08	0.42	0.39	0.06	-

^{a}Means in the same column followed by the same small letter do not significantly differ from each other by the Tukey test at the 5% error rate with respect to the shipment vibration testing time; ^{A}means in the same line followed by the same capital letter do not significantly differ from each other by the Tukey test at the 5% error rate with respect to the bottle position (layer) in the pallet; m.s.d: minimum significant difference.

Table 4. Guaraná 2 - carbonation volume.

Vibration testing	Carbonation volume (v/v)				
	Layer 1 (at bottom)	Layer 2	Layer 3	Layer 4 (on top)	m.s.d. (5%)
Without	2.38 ± 0.04^{aA}	2.38 ± 0.04^{aA}	2.38 ± 0.04^{aA}	2.38 ± 0.04^{aA}	0.06
1 h	2.40 ± 0.04^{aA}	2.32 ± 0.04^{abB}	2.29 ± 0.04^{bcB}	2.29 ± 0.04^{bB}	0.07
2 h	2.25 ± 0.04^{bB}	2.34 ± 0.05^{abA}	2.26 ± 0.01^{cB}	2.25 ± 0.03^{bB}	0.06
3 h	2.26 ± 0.03^{bB}	2.35 ± 0.01^{abA}	2.29 ± 0.03^{bcB}	2.28 ± 0.05^{bB}	0.05
3 + 48 h at 23 °C	2.30 ± 0.05^{bA}	2.29 ± 0.08^{bA}	2.34 ± 0.05^{abA}	2.28 ± 0.01^{bA}	0.09
m.s.d (5%)	0.06	0.08	0.06	0.07	-

^{a,b,c}Means in the same column followed by the same small letter do not significantly differ from each y other by the Tukey test at the 5% error rate with respect to the shipment vibration testing time; ^{A,B}means in the same line followed by the same capital letter, do not significantly differ from each other by the Tukey test at the 5% error rate with respect to bottle position position (layer) in the pallet; m.s.d: minimum significant difference.

Table 5 . Cola 2 - carbonation volume.

Vibration testing	Carbonation volume (v/v)				
	Layer 1 (at bottom)	Layer 2	Layer 3	Layer 4 (on top)	m.s.d. (5%)
Without	3.57 ± 0.13^{aA}	3.57 ± 0.13^{aA}	3.57 ± 0.13^{aA}	3.57 ± 0.13^{aA}	0.21
1 h	3.61 ± 0.03^{aA}	3.58 ± 0.07^{aA}	3.55 ± 0.05^{aA}	3.60 ± 0.05^{aA}	0.08
2 h	3.51 ± 0.03^{aA}	3.55 ± 0.04^{aA}	3.69 ± 0.12^{aB}	3.56 ± 0.05^{aA}	0.11
3 h	3.77 ± 0.09^{bA}	3.57 ± 0.03^{aB}	3.55 ± 0.03^{aB}	3.53 ± 0.03^{aB}	0.08
3 + 48 h at 23 °C	3.63 ± 0.01^{aA}	3.59 ± 0.06^{aA}	3.67 ± 0.23^{aA}	3.58 ± 0.06^{aA}	0.20
m.s.d (5%)	0.12	0.12	0.22	0.12	-

^{a,b}Means in the same column followed by the same small letter do not significantly differ from each other by the Tukey test at the 5% error rate with respect to the shipment vibration testing time; ^{A,B}means in the same line followed by the same capital letter do not significantly differ from each other by the Tukey test at a 5% error rate with respect to bottle position (layer) in the pallet; m.s.d: minimum significant difference.

analyzed. In layer 2, 48 h after the end of the test, and in layer 3 after 2 h of vibration testing, a high standard deviation was observed between the measurements due to one unit with a high carbonation loss, although this did not result in a significant variation in the statistical analysis.

For the Guaraná 2 (Table 4) samples, an influence of the shipment vibration testing time and post storage was verified, with consistent and significant results for bottles placed in layers 1 and 4. In layer 2, a significant CO_2 reduction was observed, but only 48 h after the end of the test. Since layer 3 did not show a consistent tendency for a carbonation loss with the vibration testing time, the results for the other layers must de due to variations between the sample units. With respect to Guaraná 2 after 1 h of shipment vibration lab testing, the bottle position in the load unit showed a significant tendency for a fall in the carbonation volume of the CSD as the bottle position rose in the load unit.

For the Cola 2 (Table 5) samples, the bottle position in the load unit showed a consistent and significant influence only after 3 h of shipment vibration testing.

The carbonation level in three of the four samples analyzed showed no significant influence of the transport simulation time or of the bottle position in the pallet. A significant loss was only verified in the beverage carbonation level of the Guaraná 2 samples after 1 - 2 h of shipment vibration testing. However, determinations made 3 h after transport simulation and 48 h after the end of testing did not confirm these results. The lower initial carbonation level in the Guaraná 2 samples may have resulted in a greater sensibility to small changes in these values, resulting in a differentiated performance of this sample.

4 Conclusions

The results showed that truck shipment of around 2,400 km, independent of the load over the bottle (stacking position), considering the standard stacking procedure (4 layers), had no significant influence on the carbonation level of the soft drinks (Guaraná and Cola flavours) in PET bottles with a capacity of 2 L or more. This means that the impact occurring during transport did not promote leakages in the closure system studied.

More studies are recommended in order to evaluate the influence of other variables related to the product distribution which could reduce its quality, such as truck type, road conditions and temperature variations, since the load can be exposed to excessive heat during the shipment, storage and distribution stages in tropical countries.

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References

ACIRRAM-SE as disputas. **Embanews**, São Paulo, v. 9, n. 103, p. 50-52, fev. 1999.

AMERICAN SOCIETY FOR TESTING AND MATERIALS - ASTM. **D 2911-94: Standard Specifi cation for Dimensions and Tolerances for Plastic Bottles.** Philadelphia: ASTM, 2005. 16 p.

AMERICAN SOCIETY FOR TESTING AND MATERIALS - ASTM. **D 4728-06**: **Standard Test Method for Random Vibration Testing of Shipping Container**. Philadelphia: ASTM, 2006. 7 p.

AMERICAN SOCIETY FOR TESTING AND MATERIALS – ASTM. F 1115-95: **Standard Test Method for Determining the Carbon Dioxide Loss of Beverage Bottle.** Philadelphia: ASTM, 2008. 11 p.

DATAMARK. **Carbonated Beverages – Market Development (on-line).** Disponível em: <http://www.datamark.com.br>. Acesso em: 03 fev. 2009.

FUNDAÇÃO INSTITUTO DE PESQUISAS ECONÔMICAS - FIPE. **Panorama da Indústria de Refrigerantes e Bebidas Alcoólicas no Brasil**. Disponível em: <http://www.abir.org.br/IMG/pdf/doc-165.pdf>. Acesso em: 02 fev. 2009.

GARCIA, E. E. C.; PADULA, M.; SARANTÓPOULOS, C. I. G. L. **Embalagens Plásticas**: **Propriedades de Barreira**. Campinas: CETEA/ITAL, 1989. 44 p.

INTERNATIONAL SAFE TRANSIT ASSOCIATION – ISTA. Procedure 3E: unitized loads of same products. In: INTERNATIONAL SAFE TRANSIT ASSOCIATION. **Resource Book**. East Lansing: ISTA, 2008. 14 p.

MARTINO, D. B. Caminhões adequados otimizam distribuição de bebidas. **Engarrafador Moderno**, São Paulo, v. 10, n. 67, p. 38-47, 1999.

NOBILE, M. A. del; MENSITIERI, G.; NICOLAIS, L.; MASI, P. The influence of the thermal history on the shelf life of carbonated beverages bottled in plastic bottles. **Journal of Food Engineering**, St. Louis, v. 34, n. 1, p. 1-13. 1997.

SARANTÓPOULOS, C. I. G. L.; OLIVEIRA, L. M.; QUEIROZ, G. C. Efeito da vibração do transporte rodoviário no teor de carbonatação de refrigerantes em garrafas PET 2L. In: CONGRESSO BRASILEIRO DE POLÍMEROS, 7., 2003, Belo Horizonte. **Anais**... São Carlos: ABPol, 2003. p. 7-8. CD ROM.