The Status of Modified Atmospheres (MA) and Controlled Atmospheres (CA) in Developing Countries

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Abstract
Development in the world in general is not very consistent nor uniform and much less well defined, and therefore it is very difficult to establish a very clear geographical classification for “developing” and “developed” countries. Some countries in continents generally considered as “developing” (Africa, Asia, Latin America) or some parts in these countries are as developed or more developed than certain countries or parts of countries in continents considered as “developed” (North America, Europe, Oceania). For simplification in this article, “developing countries” will denote those in Africa, Latin America and Asia except Japan and Singapore. MA and CA in their different applications (storage, marine transport, and packaging) have been used in some of the Developing Countries (DCs) for many years. For example, the use of MA for storage and packaging of different types of foods, although not in the form we know and apply today, has been used in ancient nations such as China, Egypt, Turkey and Mexico for hundreds of years. MA and CA, in their forms developed in the last 3-7 decades, have been used in several DCs for marine transport of several perishable foods and for storage of few commodities (mostly apples) for at least the last 4 decades. However, packaging in MA in an adequate form is still not practiced properly. Although there is a strong need for them and a strong potential for their development, all the 3 main applications of MA and CA in DCs, especially the packaging application, have not been developed nor used very well in the last several years due to several obstacles, among the most important are the very weak establishment and application of the cold chain, and very weak research and development, education, extension and awareness activities in these countries. This article will give an overview of the application of the different forms of MA and CA in DCs, the problems they are facing, and some recommendations for their improvement.

INTRODUCTION
Development in the world in general these days is not very consistent nor uniform and much less well defined, and therefore it is very difficult to establish a very clear geographical classification for “developing” and “developed” countries. Some countries in continents considered as “developing” (Africa, Asia, Latin America) or some parts in these countries are as developed or more developed than certain countries or parts of countries in continents considered as “developed” (North America, Europe, Oceania). In this presentation and for simplification, “developing countries” (DCs) will denote those in Africa, Latin America and Asia except Japan and Singapore.

The term “Developing Countries” (DCs) is commonly used, as well as some other terms indicating similar concepts such as “under developed countries” (used in previous years and modified later to other terms such as “less developed countries”, “least developed countries”). However, none of these terms is well defined, and there are no clear indications to classify the world into developing and developed nations.

Whatever the indications for classifications are, there are certain characteristics of what anyone can think of as DCs, among which 1) the developing world is very populous...
compared to developed world, and this problem will be even more noticeable in the future (Table 1); 2) food insecurity has been a problem in DCs and unfortunately there has not been significant improvement with more than 800 million suffering from hunger most of them in DCs (FAO Stat, 2013); 3) DCs still suffer from very significant losses and waste of food, resulting in the worsening of the food insecurity problems (Table 1); 4) DCs still lack technical capacity, infrastructure and knowhow of important techniques and technologies that are important for food preservation, such as the cold chain (Table 1).

There are very important reasons for the need of techniques and technologies such as MA and CA in DCs, including:

1. Most horticultural commodities are produced in DCs. Table 2 indicates that most world fruits and vegetables are produced in DCs. For example, 85.5% of total fruits, 76.8% of total vegetables, 80.3% of roots and tubers, 81.5% of citrus, 97.8% of tropical fruits, 94.5% of bananas, 98.4% of pineapples, 98.7% of mangoes and mangosteens, 99.5% of dates, 71.9% of apples and 80.4% of pears are produced in DCs. The production of such enormous quantities of perishable foods requires important proper techniques and technologies, such as MA and CA, for their preservation.

2. Horticultural crop production is an important economic sector in many DCs, and in fact it is the most important or even the only one in some DCs.

3. Most DCs are either exporters or trying very hard to export perishable foods. Export of perishable food commodities requires the use of important techniques such as MA and CA especially during marine transport.

4. Many DCs are far away from important export markets/countries, and therefore the use of marine transport may need the use of MA and CA.

5. Most of the population in DCs are in great need for improved nutritional and health status, and therefore there is a strong need for techniques and technologies, such as MA and CA, that can maintain the nutritional status of food in these countries and reduce their qualitative and quantitative losses.

There are very significant losses (during the early stages of the supply chain) and waste (during the later stages of the supply chain, including retailing and consumption) in horticultural commodities in DCs (Table 1). It is believed that there are much more food losses in DCs than in the developed world. In contrast, with food waste been generally more in developed than in DCs, although there are exceptions food waste being a characteristic of affluent societies in Developed or DCs. The reasons for more food losses are diverse but the lack of adequate infrastructure and proper postharvest handling techniques such as the cold chain and MA and CA, are very important (Yahia, 2006b).

However, although there is obvious need for MA and CA in DCs, it is very important that proper decisions be made of the proper application (storage, transport, packaging), and proper system to be used, based on the specific reason and crops produced in a certain country of region. In addition, it is very important to provide the proper environment for these techniques to be used properly in DCs, such as the need for proper infrastructure and application of the cold chain, proper technology transfer, proper handling of the technology especially with regard to providing proper operation and proper maintenance. Adequate investment schemes are also required.

MA and CA are complimentary techniques to the use of refrigeration and cannot be considered as alternatives (Yahia, 2019). Therefore, the application of all forms of MA and CA requires more and better use of the cold chain in DCs. However, unfortunately cold chain availability and application are very low in most DCs (Table 1). Refrigerated storage capacity is only 19 m³/1000 inhabitants in DCs, compared to 52 m³ globally and 200 m³ in the developed world. Therefore, much more increase in the cold chain infrastructure and much better application including the use of adequate systems, proper operation and maintenance, should be significantly increased and improved in DCs.

All MA and CA applications (storage, transport, packaging) have been used in DCs (Yahia, 2009, 2007, 2006a, 1993). However, several obstacles face their proper applications, including:
1. Very weak infrastructure and application of the cold chain; 
2. Very weak R&D, and technology transfer; 

MA and CA in its different applications (storage, marine transport, and packaging) have been used in some of DCs for many years. For example, the use of MA for storage and packaging of different types of foods, although not in the form we know and apply today, has been used in ancient nations such as China, Egypt, Turkey and Mexico for hundreds of years. MA and CA, in their forms developed in the last 3-7 decades, have been used in several DCs for marine transport of several perishable foods and for storage of few of these commodities (mostly apples) for at least the last 4 decades. However, packaging in MA in an adequate form is still not practiced properly (Yahia, 2009, 2007).

MA AND CA FOR STORAGE

MA for storage is hundreds of years old in some of the currently defined as DCs such as China, Egypt, Mexico, and Turkey. Currently, CA storage is used in several DCs (for the last about 40 years), such as South Africa, Chile, Mexico, Brazil, Turkey, Argentina, Uruguay, Jordan, Morocco, and India. Few countries have introduced the technology without success, indicating a clear problem of lack of proper technology transfer means, characteristics of most DCs.

In most countries where MA and CA have been used for storage, the technology used has been classical, started several years ago with the use of techniques generating nitrogen from propane, and only very few DCs have used new, improved technologies such as dynamic CA. The technology has been used almost exclusively for apples, and only very few have also used for it small quantities of few other commodities such as kiwi fruit (in Chile) and pomegranates (in Turkey). In general, the development of CA storage technology in DCs has been very slow, and no fast development is expected in most countries, except probably in China and India.

CA for storage started in Mexico in 1980 (Yahia, 1993). The system is used almost exclusively (>95%) in one single northern state (Chihuahua), and only for apple. A significant increase of the technology has occurred about 10-15 years ago, and currently about 50% of the apples produced in the country is stored under CA (Table 3). Classical CA system (using membranes to separate air and lime to remove excessive CO₂) is currently used. There are limited possibilities for development of CA for storage in other parts of the country, basically because apple production is very restricted to the north of the country (mostly in the State of Chihuahua).

CA for storage in Chile started in the 1970s, mostly for apples, but some pears and kiwi fruit have also been stored in CA. There has been excellent development, especially during the 1980s-2000s. ‘Gala’ apples are stored for 3-8 months with 1 g/m³ 1-MCP. ‘Granny Smith’ apples are stored for 5-7 months with 2000 ppm DPA or 1 g/m³ of 1-MCP, or both. ‘Red Delicious’ apples are stored for 5-8 months with 1500 ppm DPA. ‘Fuji’ and ‘Pink Lady’ apples are stored for shorter durations. ‘Packam’s Triumph’ pears are stored for 5-8 months. Dynamic CA is incipient, but growing for ‘Granny Smith’ and ‘Gala’ apples.

In Turkey, 75,000 metric tons of fruits are currently been stored in CA, among which 50,000 tons are apples, 20,000 tons are pears, and 5,000 tons are pomegranates. These stores are located in Isparta (21,000 tons), Antalya (20,000 tons), Izmir (15,000 tons), Bursa (15,000 tons), and Kahramanmaras (2,000 tons). The quantities of fruits stored in CA is still not very significant considering that cold storage capacity in the country is 1,365,987 MT. In India, about 80,000 MT of CA storage capacity has been established in the last 4-5 years. Recently Adani Group has set up three CA stores with an investment of about USS 40 million at three locations i.e., Rampur, Sainj and Rohru in Himachal Pradesh, North India. These stores have a storage capacity of 18,000 MT of apple, the largest of its kind in India. Potential more development is expected in India, both in capacity of stored fruit as well as in developed technologies and systems. CA technology has been introduced in Morocco in the early 1990s for the storage of apples.
and pears, some trials of using CA for table grapes were made several years ago. CA storage capacity in the country is about 10,000 MT, including 3,000 MT by Znibber group in Meknes, 2,500 MT by Socamar in Casablanca, 2,500 MT by Frigos Tarik in Casablanca. Therefore, the use of CA storage in the country is still very little considering the local production of more than 500,000 tons of deciduous fruits where apples represent over 350,000 tons annually. In Saudi Arabia CA facilities were introduced by 2 companies (Tabook, Wattania), but yet to be used for the purpose. In Egypt, some CA rooms have been built in the 1990s, but almost never used as CA rooms, and some rooms are currently available in Multifruit Cold Stores near Abu Ore City, but not used as CA rooms. These cases, and several others in some other DCs are examples of the lack of proper technology transfer mechanisms and proper operations and maintenance schemes, characteristics of most DCs.

MA AND CA FOR TRANSPORT

MA and CA for marine transport have been used in some DCs for several years, such as banana and tropical fruits transport from Central and South America to Europe, and mango to Europe and Asia. Banavac, a MA technique used to pack banana in a reduced pressure, has been utilized for the last 4 decades to ship the fruit over long distances. The technique has been first used for banana produced in Central and South America and currently used in several other regions. It is a simple technique where air is eliminated from around packed fruit where a polyethylene liner is used in the box to maintain a modified atmosphere. Several other systems have been used, including means to modify the atmosphere of the marine container. The use of MA and CA for marine transport has increased in the mid-1980s due to the use of better air separation and gas monitoring techniques. Several systems using different mechanisms for atmosphere modification and control have since been developed and used in different DCs and some are still being used, but with diverse difficulties. These difficulties include continuous change in systems provided and even the disappearance of several, the very poor support given by some service providers, and the lack of use and proper control of adequate atmospheres for the different commodities, especially with regard to different conditions (different cultivars, ripening stages, different origins, etc.). These problems have created inconsistency in the use of the technology, very mixed results, confusion about the efficacy of the technology, and loss of trust in it.

However, the technology of transport in MA and CA is very much needed in DCs, especially to promote the use of the less expensive marine transport and to avoid the need for the use of the expensive air transport. To demonstrate the importance of using marine transport to ship perishables from DCs and where MA and CA can be a very important support, the cost of marine transport from Chile to other markets is 10 times less expensive than air transport (Table 4).

As examples for the use of MA and CA during marine transport, in Costa Rica MA/CA is used for sea shipping of exported fruits, especially bananas. MA and CA for transport started to be used in Mexico in the mid-1970s for mango shipments to Japan, and later for avocado, and some limes and melons to Europe and Asia. Most MA and CA containers for Mexican avocados are currently shipped from the ports of Altamira, Manzanillo, and Lazaro Cardenas. In Chile, CA and MA transport systems have been used for apples, avocados and stone fruits. An atmosphere containing 12-15% CO₂ and 4-7% O₂ has been used for peaches and nectarines. In Malaysia, MA/CA is used to export ‘Cavendish’ banana using the Banavac technique.

MA AND CA FOR PACKAGING

There is very little use of MA and CA in packaging of food in general and horticultural commodities in particular in DCs (Yahia, 2007). Most of the MA applications for packaging in DCs are very simple, mostly nothing but packaging the commodities in different plastic materials, especially polyethylene. There are some cases where vacuum is used to reduce the pressure inside the plastic packages.
The lack or little use of MA and CA for packaging in DCs is due to several reasons, among the most important are the little use of the cold chain, the marketing methods commonly practiced in most DCs, lack of adequate knowledge, lack of proper technology transfer and development, and deficient extension and awareness systems.

**RESEARCH ON MA AND CA IN DCS**

Research on MA and CA in DCs, especially basic research and systems development is minimal. Most of the little research has been practical, done in laboratory, mostly for academic purposes, and there has been very little or no collaboration with the industry. Some of the DCs where some research on MA and CA has been done include Mexico, Chile, South Africa, Malaysia, Turkey, China, Chinese Taipei, Thailand, and Morocco.

**IMPORTANT REASONS/OBSTACLES FACING THE ADEQUATE ESTABLISHMENT, AND ADEQUATE APPLICATION OF MA AND CA IN DCS**

Although there is a strong need and a strong potential for the development of all the applications of MA and CA in DCs, they have not been developed very well in the last several years due to several obstacles, including:

1. Very weak infrastructure and application of the cold chain. The use of all forms of MA and CA require an adequate infrastructure and adequate application of the cold chain, as MA and CA are only complimentary techniques to the cold chain and cannot be a substitution. Therefore, the very weak cold chain in the DCs (Table 1) is a strong obstacle for the proper establishment of the technologies of MA and CA, especially for packaging.

2. Very weak R&D. Research and development in general and on MA and CA in particular are very weak in DCs resulting in difficulties in using such important technologies.

3. Very weak technology transfer systems. The weak technology transfer systems characteristics in most DCs not only did not allow the introduction of adequate technologies, but also prevented the proper establishment of introduced technologies. For example, few CA installations introduced in some DCs have never been used as CA rooms especially due to lack of knowledge of operation and maintenance.

4. Very weak education, extension and awareness programs. Education on postharvest technology in general has improved in DCs in the last years, but still very little (Yahia, 2006b) and that on proper technologies such as MA and CA is even less. Extension, in general, is very weak and on postharvest and on technologies such as MA and CA is almost lacking in most DCs, and awareness, especially for the industry is practically inexistent in many DCs.

5. Minimal investments. Investments needed for the sector especially for CA storage is generally not available in many DCs, especially due to the little or lack of involvement by the private sector in these activities in several DCs.

6. Rapid system evolution. Some deficiencies of providing the service of transport in MA and CA, such as fast changes and even disappearance of some systems, and lack of knowledge of the shippers in DCs about the systems provided and their characteristics and how they function.

7. Lack of sufficient research on tropical crops. Very insufficient research on CA storage of tropical and subtropical fruits reduced the possibility of using the technology for these important commodities (Yahia and Paull, 1997).

**CONCLUSIONS AND RECOMMENDATIONS**

There is a very strong need to increase the use of proper cold chain systems, which are essential for the application of the different MA and CA systems.

There is a strong need for the use of proper technologies in DCs, such as MA and CA, that can maintain foods and reduce their quantitative and qualitative losses and waste to achieve food security.
There is a need for better education, extension and awareness systems especially for the industry. There is a need for the industry to understand the systems provided to be able to make proper decision of what system to use, when and how to use them properly.

Research in DCs on MA and CA should be increased and improved, especially with regard to better objectives of the research and more coordination between the different sectors, especially between the research institutions and the industry.

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Literature Cited

### Tables

Table 1. Differences between developing and developed world with regard to population, refrigeration capacity and food losses (International Institute of Refrigeration, 2011).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Global</th>
<th>Developed countries</th>
<th>Developing countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population in 2009 (billion inhabitants)</td>
<td>6.83</td>
<td>1.33</td>
<td>5.6</td>
</tr>
<tr>
<td>Population in 2050 (forecast, billion inhabitants)</td>
<td>9.15</td>
<td>1.28</td>
<td>7.87</td>
</tr>
<tr>
<td>Refrigerated storage capacity (m$^3$/1000 inhabitants)</td>
<td>52</td>
<td>200</td>
<td>19</td>
</tr>
<tr>
<td>% Food losses (all products)</td>
<td>25</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>% Losses of fruits and vegetables</td>
<td>35</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>% Losses of perishable foods due to lack of refrigeration</td>
<td>20</td>
<td>9</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 2. Proportions of some fruits and vegetables produced in developing and developed countries (FAO-STAT, 2013).

<table>
<thead>
<tr>
<th>Commodities</th>
<th>Developing countries</th>
<th>Developed countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetables (total)</td>
<td>76.8</td>
<td>13.2</td>
</tr>
<tr>
<td>Fruits (total)</td>
<td>85.8</td>
<td>14.2</td>
</tr>
<tr>
<td>Roots and tubers</td>
<td>80.3</td>
<td>19.7</td>
</tr>
<tr>
<td>Citrus</td>
<td>81.5</td>
<td>18.5</td>
</tr>
<tr>
<td>Tomatoes</td>
<td>52.5</td>
<td>47.5</td>
</tr>
<tr>
<td>Tropical fruits</td>
<td>97.8</td>
<td>2.2</td>
</tr>
<tr>
<td>Bananas</td>
<td>94.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Pineapples</td>
<td>98.4</td>
<td>1.6</td>
</tr>
<tr>
<td>Papayas</td>
<td>98.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Mango and mangosteen</td>
<td>99.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Dates</td>
<td>99.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Apples</td>
<td>71.9</td>
<td>28.1</td>
</tr>
<tr>
<td>Pears</td>
<td>80.4</td>
<td>19.6</td>
</tr>
</tbody>
</table>

Table 3. Total quantities of apples stored in refrigerated air and in controlled atmosphere in Mexico (courtesy of Dr. Jesus Ornelas-Paz).

<table>
<thead>
<tr>
<th>Stored apples (MT)</th>
<th>Total</th>
<th>In refrigeration only</th>
<th>In controlled atmospheres</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>621,157</td>
<td>289,518</td>
<td>331,639</td>
</tr>
</tbody>
</table>
Table 4. Cost of air and marine transport (US$/kg) from Chile to different markets (courtesy of Dr. Juan Pablo Zoffoli).

<table>
<thead>
<tr>
<th>Market</th>
<th>Air transport</th>
<th>Marine transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>1.6</td>
<td>0.28</td>
</tr>
<tr>
<td>Europe</td>
<td>2.5</td>
<td>0.26</td>
</tr>
<tr>
<td>Asia</td>
<td>3.2</td>
<td>0.37</td>
</tr>
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