Volume: 1, Issue: 1, 2022, pp. 21-32
E - ISSN: 2822-5228
URL: https://journals.gen.tr/index.php/jgcc/index
DOI: 10.56768/jytp.1.1.04

Received: 10.05.2022
Accepted: 01.07.2022

ORIGINAL ARTICLE

Review of phase change materials as an environmental approach for postharvest fruit and vegetable cold storage

Tuğba Güngör Ertuğral

1 Canakkale Onsekiz Mart University, Canakkale Faculty of Applied Sciences, Türkiye, e-mail: tugbagungor@comu.edu.tr

ABSTRACT

Today, nearly half of food products are decreasing before reaching to consumer and data shows that one third of food never reaches to end consumer. It is known that % 50 of these are caused by technical errors, temperature management and reducing postharvest losses will play important role of world population in future. Therefore, preventing or minimizing loss of fresh fruits and vegetables has become important issue. Petroleum fuels and electrical energy cold storages are costly and causes environmental pollution. Recently, phase change material (PCM) is clean, environmentally friendly and renewable energy source and interesting material in energy systems. PCMs have ability to store ambient heat as latent heat energy and return the stored latent heat energy during rising and falling to ambient temperature. Accurate phase change temperature range PCMs work as low and high temperature barriers, providing maximum energy savings as an economical storage system and can prevent carbon (C) emissions by reducing environmental pollution. This study is a review of applicable thermal energy storage PCM materials for cold storage of postharvest fresh fruits and vegetables and aims reduce to C emission and energy saving.

Keywords: Phase change material, Thermal energy storage, Cold storage, C emission, Energy saving

Citation: ERTUĞRAL GÜNGÖR, T., Review of phase change materials as an environmental approach for postharvest fruit and vegetable cold storage. *Journal of Global Climate Change.* 2022; 1(1): 21-32, DOI: 10.56768/jytp.1.1.04

Corresponding Author:
Tuğba Güngör Ertuğral
Email: tugbagungor@comu.edu.tr

1. INTRODUCTION

World population will reach 9.6 billion by 2050 and consequently % 70 more food production will be required (Krishnan et al., 2020). As parallel with increase world population, demand for vegetables and fruits is also increasing. According to United Nations Food and Agriculture Organization (FAO) 2016 data, 865.8 million tons of fresh fruit production in 65.2 million hectares and 1 billion tons of fresh vegetables were produced in 57 million hectares of land in the world. Especially tomato is most produced vegetable that was 182,301,395 tons in 2017 (FAO 2019a). Almost half of cultivated products are lost before they even reach consumption stage. In the future, post-harvest reducing play an important role on world pop- ulation (Gustavsson et al., 2011). From this point of view, preventing or at least minimizing loss of fresh fruits and vegetables becomes an important issue. The loss rate of fresh fruits and vegetables, which are perishable products, %50 reaches result of disruptions and misapplications in harvest-transport-cooling-packaging-storage-transportsales chain (Sorhocam, 2020). Most factors (processing, storage and transport conditions) play important role in deterioration reactions of fruits and vegetables on their transport from grower to consumer. If these factors are not properly controlled, there will be large post-har- vest losses (Table 1). Changes in fresh products cannot be stopped, but it is possible to minimize losses with low temperature, relative humidity control, appropriate packaging and transporta- tion measures (Ahmad and Siddiqui, 2015). On the other hand, thermal energy storage (TED) materials, can be used efficiently when lack of resources to produce energy or with cooling systems that are opened at 4-5hour intervals. PCM design and implementation of food safety sys- tem has attracted great interest in recent years. Using these technologies minimizing food waste enables optimal planning of distribution networks and this reduces the carbon emissions of the entire supply chain.

2. SOME FRUIT AND VEGETABLE POSTHARVEST LOSSES

Increasing shelf life of products, including thermal or refrigerated packaging methods, from production center to point of consumption and main parts of cold chain, which is a logistics system that provides most ideal conditions for perishable products to maintain its quality that are as follows:

•Food processing (eg freezing of some processed foods)

•Cold storage (short or longterm storage of frozen foods)

•Distribution (refrigerated shipping and temporary storage in temperature controlled conditions)

•Marketing (in wholesale markets, retail markets and food service businesses, it is the placing of the product in warehouses and showcases with refrigerators or freezers (Postharvest, 2017).

If storage and transportation conditions are not followed in cold chain from the grower to consumer, post-harvest losses increase. Lowering temperature and controlling relative humidity can reduce losses (Ahmad and Siddiqui, 2015). Moisture loss, bruising and subsequent spoilage are types of spoilage that cause fresh fruit and vegetables to be discarded (Kitinoja and Al-Hassan, 2010; Ray and Ravi, 2005). Production and marketing losses are experienced in stages between the production and consumption of all fresh fruits and vegetables, especially tomatoes and for example Turkey marketing loss of 12 billion TL/year than fresh fruit and vegetables (FAOSTAT, 2019). Cold storage applications have become inevitable and necessary to reach markets. Depending on these developments; world cold storage capacity has reached 552 million m3 (Salin, 2010; Cantek, 2016). Post-harvest product losses in developed countries are less than in yet developing countries (Table 1, 2) (Erkan, 2021).

Table 1. Postharvest product losses in fresh fruits and vegetables in *developed* countries (Erkan, 2021)

Products	Loss Rates (%)
Leaf salad, iceberg	11.7
Cucumber	7.9
Sweet pepper	10.6
Tomato	14.7
Potato	4.9
Apple	1.7
Pear	4.1
Peach	12.6
Strawberry	22
Orange	10-12

Table 2. Postharvest product losses in fresh fruits and vegetables in developing countries (Erkan, 2021).

Products	Loss Rates (%)
Lettuce, Leaf salad	62
Cabbage	37
Cauliflower	49
Tomato	20-50
Onion	16-35
Potato	5-40
Apple	14
Peach	28
Grape	20-95
Citrus	23-33
Banana	20-80

3. COLD STORAGE APPLICATIONS AND ENERGY USE TO POSTHARVEST FRUIT AND VEGETABLES

It is known that nearly fifty percent of these losses are caused by technical errors related to control and temperature management. Cold air technologies are important in logistics and temperature of sensitive food products. Microbiological and chemical deterioration occur with temperature fluctuations in cold chain so as mostly at transportation vehicles or transportation transitions (İzer, 2017). Although insulating cooling equipment is used to reduce this risk, there is no latent heat storage feature at low temperatures. After harvest, fruits and vegetables survive and perform all functions of a living tissue (Joas and L´ecaudel, 2008). Increasing the quality of fresh fruits and vegetables cannot be changed, provided that naturalness is preserved in terms of technology, it is only preserved (Tigist, 2013). The postharvest treatment methods that must be followed to maintain this quality are as follows; methylcyclopropene (1-MCP), calcium Chloride (CaCl2) application, modified atmosphere packaging (MAP), tomato postharvest heat treatment, cooling storage (Arah et al., 2016).

The determination of harvest maturity stage depends on desired market target and time required to fruit market. The most effective factor in hardness change after fruits harvest is ambient temperature and temperature rises, the hardness values decrease rapidly. For this reason, strength of harvested fruits can be increased by moving them from field or garden to a cool place (Mercan, 2005). Although plants produce pathogenic bacteria, pectolytic and softening enzymes, most of bacteria that cause soft rot in many products belong to certain Erwinia species (Aysan et al., 2003). Erwinia carotovora subsp. carotovora (Jones) Dye and Erwinia carotovora subsp. atroseptica (van Hall) Dye (soft rot): They are most important bacterial diseases that cause damage to many crops, especially tomatoes and peppers. One of the most easily recognized mold fungi is Alternaria ssp. (Kadakal et al., 2011). These patho- gens are spread by splashing water on soil, wind, harvest and postharvest processes. Bacteria pass- es from a rotten product to healthy product by flow. Packaging fresh fruits and vegetables can reduce food losses with better and smarter packaging design to keep food fresh longer.

Therefore, suitable packaging systems should be designed (Elik et al., 2019). In developing countries, lack of cooling system is seen as main cause of postharvest losses (FAO, 2013).

The world cold storage capacity has reached 552 million m3. In this capacity, India (133 million m3), USA (114 million m3) and China (76 million m3) occupy top three places and Turkey ranks 13th with Spain, which has same capacity, with a capacity of 7 million m3. While total growth was % 5 in 17 countries where cold air investments are concentrated growth was % 10 in Turkey, India, Peru and China. Cooling; for perishable horticultural crops, it reduces respira- tion, reduces spoilage and natural ripening rates, slows down ripening by reducing transpiration, water loss, wrinkling, as well as ethylene produc- tion, reduces activities of microorganisms, black- ening, loss of texture, taste and nutritional value (Kitinoja and Kader, 2015). Cooling systems consume electrical energy, about % 40 of total energy consumption (Sarafoji et al., 2021). Traditionally, vapor compression refrigeration cycles are used in cold stores (Üçgül, 2009). In this cycle, energy required for compression work in compressor is met by electrical energy. Among other energy sources, electrical energy is seen as cleanest source in terms of environmental impact. However, this is not case when electrical energy is considered as a source of generation. In many countries around the world, electrical energy is still produced in thermal power plants and using fossil fuels. This situation reveals that there is an indirect environmental polluting effect in electrical energy. For example, Turkey produces approximately % 75 of its electricity in thermal power plants that use fossil fuels (UNDP, 2006; Tarakcıoğlu, 1984; TUSIAD, 1998). The indirect environmental impact arising from use of electrical energy is a subject that must be examined.

Examination of export problems of South African fruit producers from Cape Town port with refrigerated ship containers over the port, it has been determined that one of the important factors in quality of fruits and product losses is temperature changes they are exposed to when the refrigerated container is loaded from cold storage while on truck and containers are plugged into power source during transfer of containers from truck to ship at port. In addition, design of cooling system in refrigerated ship containers is sufficient to maintain a certain temperature but because it is not sufficient for cooling, the importance of loading the fruits into these containers at recommended coldness. İmportance of initial cooling and critical importance of maintaining temperature reached here throughout entire transport are expressed in same research (Goedhals-Gerber et al., 2015).

Temperature is main determining factor for shelf life and product quality in food cold chain. As an alternative, active refrigerator boxes can be used, provided batteries are charged and active cold pack box systems that can cool provided that cold packs are replaced or dry ice is added and replaced to control system batteries (Rong et al., 2011). Especially in domestic transportation, non-refrigerated vehicles are used, so cold chain/ air conditioning cannot be applied. The solution proposal is; It is envisaged to expand vehicle tracking systems and heat recording devices in fresh fruit and vegetable transportation, especially refrigerated vehicle transportation and to ensure traceability of products. In a different study total logistics cost of okra after harvest was calculated as 2,191,978.56 TL/500kg (Çakır, 2019) and cost of an integrated ice store in a 3ton chiller was subtracted and amortization period was determined for a "partial storage" application. Cold storage system electricity consumption in 8 hours can cost amounting to 4,971,700 TL to 41.5 kWh (Basaran and Erek, 2001). Mechanical systems used in refrigerated transportation are not shut down under any circumstances and desired set interval value is not exceeded, two drivers are used, thus preventing cold chain from being broken since electrical energy taken from vehicle is not cut off. In short-term transportation applications, driver is obliged to leave vehicle in working condition during meals or short-term stays.

In addition, fuel consumption increases as a high cooling load is brought to refrigerated vehicle (Kılıç, 2018). Conventional vapor compression refrigeration systems cause 0.585 kg of carbon dioxide (CO2) to be released into the atmosphere to produce 1kWh cold effect, also cost for 1kWh cooling effect is 0.016 Euro/kWh (SE) for ejector system and 0.178 Euro/kWh (SE) for con- ventional cooling system (Üçgül, 2009).

4. PCMS ROLE IN ENERGY USE AND ITS IMPACT ON C EMISSIONS

Heat energy can be stored as sensible, latent and thermochemical energy. Latent heat storage is most interesting method. PCMs are substances that can absorb and store heat during the phase change process and dissipate this stored heat in case of reverse phase change (Tao et al., 2008; Boan, 2005). The phase change is basically caused by temperature change caused by heat source coming from stable state of substance. In latent heat storage technique, PCMs have energy storage/release function during phase change at specified temperature. PCMs have an important place with high energy storage, isothermality and controlled phase change (Zalba et al., 2003; Kenisarin and Mahkamov, 2007).

Many organic and inorganic PCMs and their mixtures (Fig.1) are used in solar heating (water, building etc.) and temperature regulation in textiles, thermal management of electronics, biomedical and biological transport systems, etc. PCMs have high impact strength and chemical resistance (Alkan et al., 2006). PCMs are nowadays used in solar energy storage, heat pumps, heating and air conditioning in buildings, heat distribution systems, etc. widely used in the fields. Studies on PCM microcapsules have increased in the last 10 years (Gulfam et al., 2020).

Preparation of new generation materials with modified PCM studies, for example, a new PCM was synthesized by connecting polyethylene terephthalate to polyethylene glycol (Gungor Ertugral and Alkan, 2021). In solid-liquid phase change, food packaging containing PCM in solid state can minimize temperature fluctations that can occur foodstuff (Johnston et al., 2008) also provides insulation by preventing chang- ing ambient temperature from reaching food for a long time. Organic and inorganic PCMs have been tried by many researchers to elicit maximum thermal efficiency available (Sathishkumar et al., 2020). PCM system was used to home refrigerator and compressor worked 3,566 hours a day and operating time was reduced by 45 minutes compared to previous year and it was observed that carbon dioxide emissions were reduced by % 17.4 and fossil fuel consumption by 28 kg and 12 liters per day, respectively (Zarajabad and Ahmadi, 2018). Functional food packaging materials and petroleum, electricity, etc.

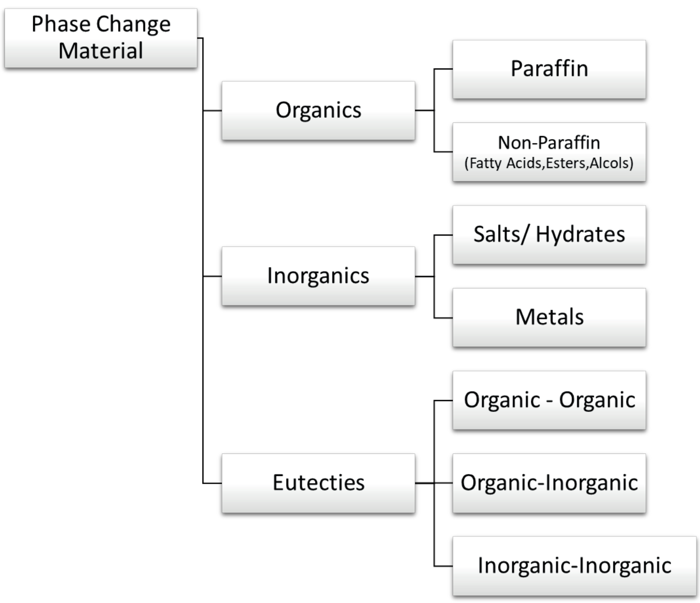

Figure 1. Classification of PCMs (Tatsidjodoung et al., 2013).

It is possible to preserve quality and safe food by using as little energy sources as possible. For this purpose, the interest in environmentally friendly, new generation, smart packaging materials that can keep food cold for a certain period time, which is beneficial to the global economy as parallel.

5.APPLICABLE PCMS TO COLD STORAGE OF POSTHARVEST FRUIT AND VEGETABLES

Appropriate PCM selection is save energy for cold chain during storage and transportation of foods. Preservation of storage temperature in range of 8-10 °C suitalbe to ripe tomatoes and it is also best storage temperature range for potatoes, citrus fruits, star fruit, melon, okra, pineapple and zucchini (Cantwell, 2001).

Various PCMs can be used as packaging material to keep temperature constant by using minimum external energy source in cold chain applications of postharvest fruits and vegetables whose storage temperatures vary between 5-18°C (Table 3).

It has been observed that a PCM plate integrated in a vertical structure reduces energy consumption by about 10 times, when plate thickness increases by 6 mm, the compressor run time ratio decreased from % 36 to % 26 (Ezan et al., 2017) and Rubitherm brand PCMs used in storage boxes for cold chain applications that have been effective in cooling (Du et al., 2020).

6. CONCLUSIONS

In recent years, PCMs have been developed in field of microencapsulation, shape stabilization and materials as nanomaterials. PCM technology has been widely studied in building, cooling, thermal management of electronic equipment and various other fields. With selection of the appropriate PCM, especially commercially available paraffin PCMs, postharvest fruits and vegetables can be stored for a long time without need for another energy source, and even in case of a solar-powered system, it is possible to build a warehouse that can cool with % 100 green energy. A system developed with smart materials without using electricity and petroleum fuel can be completely environmentally friendly. If these new generation smart materials are applied to refrigerated vehicles and continuous cooling units in food logistics, it is possible to reduce the C emulsion because less petroleum fuel and electricity will be consumed. In this way, the operating principle close to raw material, which is important for fruit and vegetable industry can be changed by cheap and economical trans- portation systems. Decrease in transportation costs, which are reflected in food prices in con- sumer society, cheaper food consumption can be achieved and opportunity for healthy nutrition increases. Green energy systems supported by natural energy sources such as solar energy or wind energy supported by PCMs instead of petroleum-derived fuels that cause environmental pollution can provide economical food consumption and a clean environment.

Table 3. Applicable PCMs preservation for postharvest fruit and vegetable

PCM	**Tm˚C**	**Latent Heat (J/g)**	
Tetrahydrofuran	5	280	Yang et al., 2018.
n-Tetradecane	5.5	226	Sharma, 2004.
Formic Acid	7.8	247	Sharma, 2004.
Polyethyleneglycol 400	8	99.6	Sharma, 2004.
Dimethyl adipate	9.7	164.6	Yang et al., 2018.
n-Pentadecane	10	205	Sharma, 2004.
D2O	3.7	318	Sharma, 2004.
LiClO4.3H2O	8	253	Sharma, 2004.
NH4Cl.Na2SO4.10H2O	11	163	Sharma, 2004.
Caprylic acid + 1-dodecanol (70:30) 6.52 171.06	6.52	171	Zuo et al.,2011
Caprylic alcohol + Mynstyl alcohol (73.7:26.3 by mass)	6.9	169	Wu et al., 2015.
Lauryl alcohol + Octanoic acids (40.6:59.4)	7	179	Hu et al., 2011.
Capric acid and lauric acid (65:35 by mole) + Pentadecane (50:50 by volume)	10	158	Dimaano and Watanabe 2002.
Capric acid and lauric acid (65:35 by mole) + Pentadecane (70:30 by volume)	11	149	Dimaano and Watanabe 2002.
C5H5C6H5 + (C6H5)2O (26:73.5)	12	98	Sharma, 2004.
Capric acid and lauric acid (65:35 by mole) + 0.10 mol Cineole	12	112	Roxas-Dimaano and Watanabe, 2002.
Capric acid and lauric acid (65:35 by mole) + 0.10 mol Methyl Salicylate	13	127	Dimaano and Watanabe 2002.
Capric acid and lauric acid (65:35 by mole) + Pentadecane (90:10 by volume)	13	142	Dimaano and Watanabe 2002.
Capric acid and lauric acid (65:35 by mole) + 0.10 mol Eugenol	13	118	Dimaano and Watanabe 2002.
Capric acid + Lauric acid-oleic acid	15	109	Jia et al., 2019

Table 3 (continue). Applicable PCMs preservation for postharvest fruit and vegetable

PCM	Tm°C	Latent Heat (J/g)	
Lauric + 1-dodecanol (29:71)	17	175	Kumar et al., 2017
Capric acid + Lauric aci (65:35 by mole)	18	140	Dimaano and Watanabe 2002.
Myristic + 1-dodecanol (17:83)	18	181	Kumar et al., 2017
31% Na2SO4 + 13% NaCl + 16% KCl + 40% H2O	4	234	Sharma, 2004.
K2SO4 + Carboxymethyl cellulose + (NaPO3)6 + borax + boric acid (76 + 10.3+ 3.6 + 2 + 3.2 + 0.1 + 2.4 + 2.4)	8.2	114	Liu et al., 2007
55% CaCl2 ·6H2O + 55% CaBr2 ·6H2O 14.7 140 [28] NaOH (3/2) H2O	15	140	Cabeza et al., 2011
Rubitherm T3(RT3) Paraffin	3	198	Rubitherm, 2021
RT4 Paraffin	4	182	Rubitherm, 2021
RT5 Paraffin	5.2	158	Rubitherm, 2021
RT6 Paraffin	6	175	Rubitherm, 2021
MPCM (6) Paraffin	6	167	Microteklabs,2021
ClimSel C7 Organic	7	130	Climator, 2021
PureTemp 8 Organic	8	180	Puretemp, 2021
PCM-OM08P Organic	8	190	Zhang et al., 2021
PCM-OM11P Organic	11	260	Zhang et al., 2021
A8 Organic	8	150	Epsltd, 2021.
RT 8 Organic	8	180	Rubitherm, 2021
RT 9 Organic	9	160	Rubitherm, 2021
A9 Organic	9	140	Epsltd, 2021.
RT10 Organic	10	150	Rubitherm, 2021
RT 10 HC Organic	10	195	Rubitherm, 2021
S1 0 Organic	10	155	Cristopia, 2021
PureTemp 12 Organic	12	185	Puretemp, 2021
RT12 Organic	12	150	Rubitherm, 2021

REFERENCES

AHMAD, M. S., & SIDDIQUI, M. W. (2015). Factors affecting postharvest quality of fresh fruits. In *Postharvest quality assurance of fruits* (pp. 7-32). Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-21197-8_2

ALKAN, C., SARI, A., & UZUN, O. (2006). Poly (ethylene glycol)/acrylic polymer blends for latent heat thermal energy storage. *AIChE journal*, *52*(9), 3310-3314. https://aiche.onlinelibrary.wiley.com/doi/epdf/10.1002/aic.10928

ARAH, I. K., AHORBO, G. K., ANKU, E. K., KUMAH, E. K., & AMAGLO, H. (2016). Postharvest handling practices and treatment methods for tomato handlers in developing countries: A mini review. *Advances in Agriculture*, *2016*. https://doi.org/10.1155/2016/6436945

Available online: www.cristopia.com (accessed on 1 September 2021).

Available online: www.epsltd.co (accessed on 1 September 2021).

Available online: www.puretemp.com (accessed on 1 September 2021).

Available online: www.climator.com (accessed on 1 September 2021).

Available online: www.rubitherm.eu (accessed on 1 September 2021).

Available online: www.microteklabs.com (accessed on 1 September 2021).

AYSAN, Y., KARATAS, A., & CINAR, O. (2003). Biological control of bacterial stem rot caused by Erwinia chrysanthemi on tomato. *Crop Protection*, *22*(6), 807-811. https://doi.org/10.1016/S0261-2194(03)00030-9.

BAŞARAN, T., & EREK, A. (2001). Bir Soğu Deposunun Ekonomik Analizi. *IV. Ulusal Tesisat Mühendisliği Kongresi ve Sergisi*.http://www1.mmo.org.tr/resimler/dosya_ekler/9774cc26d95f2b3_ek.pdf.

BOAN, Y. (2005). Physical mechanism and charactarization of smart thermal clothing. *The Hong Kong Polytechnic University, PhDThesis, Hong Kong*. https://theses.lib.polyu.edu.hk/bitstream/200/1884/1/b18967693.pdf

BO, H., GUSTAFSSON, E. M., & SETTERWALL, F. (1999). Tetradecane and hexadecane binary mixtures as phase change materials (PCMs) for cool storage in district cooling systems. *Energy*, *24*(12), 1015-1028. https://doi.org/10.1016/S0360-5442(99)00055-9

CABEZA, L. F., CASTELL, A., BARRENECHE, C. D., DE GRACIA, A., & FERNÁNDEZ, A. I. (2011). Materials used as PCM in thermal energy storage in buildings: A review. *Renewable and Sustainable Energy Reviews*, *15*(3), 1675-1695. https://doi.org/10.1016/j.rser.2010.11.018

CANTEK, 2016. Dünya Soğuk Hava Depo Kapasitesi. CANTEK GROUP Şubat Bülteni 2016/3. https://www.turktob.org.tr/dergi/makaleler/dergi17/TTOB_Dergi17_WEB-28_31.pdf

CANTWELL, M. (2001). Properties and recommended conditions for long-term storage of fresh fruits and vegetables. *Storage Recommendations, Department of Plant Sciences, University of California,Davis*.https://www.carolinafarmstewards.org/wp- content/uploads/2015/05/Properties-and-Recommended-Conditions.pdf

ÇAKIR, G. (2019). *Tarımsal ürünler tedarik zinciri yönetimi: Amasya çiçek bamyası uygulaması* (Master›s thesis, Maltepe Üniversitesi, Sosyal Bilimler Enstitüsü). http://openaccess.maltepe.edu.tr/xmlui/handle/20.500.12415/2992

DIMAANO, M. N. R., & WATANABE, T. (2002). The capric–lauric acid and pentadecane combination as phase change material for cooling applications. *Applied Thermal Engineering*, *22*(4), 365-377. https://doi.org/10.1016/S1359-4311(01)00095-3. https://doi.org/10.1016/S1359-4311(01)00095-3

DU, J., NIE, B., ZHANG, Y., DU, Z., & DING, Y. (2020). Cooling performance of a thermal energy storage-based portable box for cold chain applications. *Journal of Energy Storage*, *28*, 101238. https://doi.org/10.1016/j.est.2020.101238

ELIK, A., YANIK, D. K., ISTANBULLU, Y., GUZELSOY, N. A., YAVUZ, A., & GOGUS, F. (2019). Strategies to reduce post-harvest losses for fruits and vegetables. *Strategies*, *5*(3), 29-39. https://www.btb.org.tr/images/raporlar/13/main.pdf

ERKAN M. “Bahçe Ürünlerinde Depolama ve Muhafaza”. https://baib.gov.tr/files/downloads/PageFiles/e9a02402-d812-401a-8fe3-bea324c1003b/Files/urun%20depolama%20ve%20paketlem%20(2).pdf. Son erişim tarihi:26. Ekim.2021

EZAN, M. A., DOGANAY, E. O., YAVUZ, F. E., & TAVMAN, I. H. (2017). A numerical study on the usage of phase change material (PCM) to prolong compressor off period in a beverage cooler. Energy conversion and management, 142, 95-106. https://doi.org/10.1016/j.enconman.2017.03.032

FAO. 2013. Report of the Expert Consultation Meeting on Food Losses and Waste Reduction in the Near East Region: Towards a Regional Comprehensive Strategy, Egypt, 33p.

FAO 2019a, https://www.fao.org/documents/card/en/c/ca6030en/, Son erişim: 25.03.2022.

FAOSTAT, http://www.fao.org/faostat/en/#data/QC/visualize, Son erişim tarihi: 19 Mayıs 2019.

GOEDHALS-GERBER, L. L., HAASBROEK, L., FREIBOTH, H., & VAN DYK, F. E. (2015). An analysis of the influence of logistics activities on the export cold chain of temperature sensitive fruit through the Port of Cape Town. *Journal of Transport and Supply Chain Management*, *9*(1), 1-9. file:///C:/Users/COMU/Downloads/goedhalsgerber_analysis_2015.pdf

GUSTAVSSON, J., CEDERBERG, C., SONESSON, U., VAN OTTERDIJK, R. M., & MEYBECK, A. A. (2011) Global food losses and food waste: extent, causes and prevention. *FAO Rome*, 38. https://www.fao.org/3/I2697E/i2697e.pdf

GULFAM, R., OREJON, D., CHOI, C. H., & ZHANG, P. (2020). Phase-change slippery liquid-infused porous surfaces with thermo-responsive wetting and shedding states. *ACS Applied Materials & Interfaces*, *12*(30), 34306-34316. https://pubs.acs.org/doi/pdf/10.1021/acsami.0c06441.

GÜNGÖR ERTUĞRAL, T., & ALKAN, C. (2021). Synthesis of thermally protective PET–PEG multiblock copolymers as food packaging materials. *Polymers and Polymer Composites*, *29*(9_suppl), S1125-S1133. https://doi.org/10.1177%2F09673911211045683

GAO, H. T. (2011, May). Investigation on organic phase transition materials in Energy Storage Air Conditioning system. In *2011 International Conference on Materials for Renewable Energy & Environment* (Vol. 1, pp. 669-672). IEEE. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5930898

HU, X. C., WU, H. J., & ZHOU, X. Q. (2011). Crystallizing characteristics of binary mixtures of Dodecanol/Caprylic acid for phase change cool storage. *Journal of Guangzhou University (Natural Science Edition)*. http://en.cnki.com.cn/Article_en/CJFDTOTAL-GUDZ201102013.htm

İZER, D. A. (2017). Soğuk Zincir Lojistiği İçinde Risklerin Azaltilmasinda Yeni Teknolojiler.file:///C:/Users/COMU/Downloads/SOGUK_ZINCIR_LOJISTIGI_ICINDE_RISKLERIN%20(1).pdf

JIA, X., ZHAI, X., & CHENG, X. (2019). Thermal performance analysis and optimization of a spherical PCM capsule with pin-fins for cold storage. *Applied Thermal Engineering*, *148*, 929-938. https://doi.org/10.1016/j.applthermaleng.2018.11.105

JOAS, J., & LÉCHAUDEL, M. (2008). A comprehensive integrated approach for more effective control of tropical fruit quality. Stewart Postharvest Review, 4(2), 1-14. https://access.portico.org/stable?au=phx64r67x6b

JOHNSTON, J. H., GRINDROD, J. E., DODDS, M., & SCHIMITSCHEK, K. (2008). Composite nano-structured calcium silicate phase change materials for thermal buffering in food packaging. Current Applied Physics, 8(3-4), 508-511. https://doi.org/10.1016/j.cap.2007.10.059

KADAKAL, Ç., ARTIK, N., & SEBAHATTIN, N. A. S. (2011). Domates doku ve küf karakteristikleri, domates ürünlerinde küf sayimi ve küfü azaltma olanakları. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, *7*(2), 251-260. https://dergipark.org.tr/en/download/article-file/191366

KENISARIN, M., & MAHKAMOV, K. (2007). Solar energy storage using phase change materials. *Renewable and sustainable energy reviews*, *11*(9), 1913-1965. https://doi.org/10.1016/j.rser.2006.05.005

KRISHNAN, R., AGARWAL, R., BAJADA, C., & ARSHINDER, K. (2020). Redesigning a food supply chain for environmental sustainability–An analysis of resource use and recovery. *Journal of cleaner production*, *242*, 118374. https://doi.org/10.1016/j.jclepro.2019.118374

KILIÇ, G. A. (2018). Endüstriyel soğutma uygulamalarında ötektik soğutucuların etüdü ve parametrelerinin incelenmesi. https://dspace.balikesir.edu.tr/xmlui/bitstream/handle/20.500.12462/3285/G%C3%BClenay_Alevay_K%C4%B11%C4%B1%C3%A7.pdf?sequence=1&isAllowed=y

KITINOJA, L., & ALHASSAN, H. Y. (2010). Identification of appropriate postharvest technologies for small scale horticultural farmers and marketers in sub-Saharan Africa and South Asia-Part 1. Postharvest losses and quality assessments. In *XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on 934* (pp. 31-40). https://doi.org/10.17660/ActaHortic.2012.934.1

KITINOJA, L., & KADER, A. A. (2015). Measuring postharvest losses of fresh fruits and vegetables in developing countries. *PEF white paper*, *15*, 26. http://www.postharvest.org/PEF_White_Paper_15-02_PHFVmeasurement.pdf

KUMAR, R., VYAS, S., & DIXIT, A. (2017). Fatty acids/1-dodecanol binary eutectic phase change materials for low temperature solar thermal applications: design, development and thermal analysis. *Solar Energy*, *155*, 1373-1379. https://doi.org/10.1016/j.solener.2017.07.082

LIU, J. H., LIU, R. H., WANG, C. H., & LIANG, Y. N. (2007). Thermodynamics test of Na2SO4· 10H2O phase change compound system. *Energy Conserv*, *9*, 13-14. http://en.cnki.com.cn/Article_en/CJFDTOTAL-JNJN200709004.htm

MERCAN, T. (2005). Organik gübreleme yapılarak tarım ilacı çok kullanılmadan ve klasik yöntem uygulanarak üretilen domatesler ile bunlardan elde edilen bazı ürünlerin kalitelerinin belirlenmesi. https://acikerisim.uludag.edu.tr/bitstream/11452/5218/1/198676.pdf

POSTHARVEST. (2017). Meyve ve Sebzelerin Depolama ve Nakliye Uygulamaları Eğitim Materyali. "Gıda Zincirindeki Hasat Sonrası Kayıpları Azaltmak için Yenilikçi Yaklaşımlar". 2017-1-TR01-KA202-045709. http://www.postharvestproject.com/uploads/outputs/57acfd7e-db50-4466-bfe4-1700e847f9e3.pdf. Son erişim tarihi: 26 Ekim 2021.

RAY, R. C., & RAVI, V. (2005). Post harvest spoilage of sweetpotato in tropics and control measures. *Critical reviews in food science and nutrition*, *45*(7-8), 623-644. https://www.tandfonline.com/doi/pdf/10.1080/10408390500455516

ROXAS-DIMAANO, M. N., & WATANABE, T. (2002). The capric and lauric acid mixture with chemical additives as latent heat storage materials for cooling application. *Energy*, *27*(9), 869-888. https://doi.org/10.1016/S0360-5442(02)00024-5

ÜÇGÜL, İ. (2009). Soğuk depolama için güneş enerjili ejektör soğutma sistemi uygulamasının termodinamik çevresel ve ekonomik analizleri. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, *15*(2), 269-277. https://dergipark.org.tr/en/download/article-file/190925

RONG, A., AKKERMAN, R., & GRUNOW, M. (2011). An optimization approach for managing fresh food quality throughout the supply chain. *International Journal of Production Economics*, *131*(1),421,429. https://doi.org/10.1016/j.ijpe.2009.11.026https://www.sciencedirect.com/science/article/pii/S0925527309004290.

SALIN, V. (2010). Global cold storage capacity report. *Report for the International Association oRefrigeratedWarehouses.Alexandria:IARW*.https://login.totalweblite.com/Clients/wscbanet/database- 01%20 2010%20cold%20storage%20capacity%20report.pdf.

SARAFOJI, P., MARIAPPAN, V., ANISH, R., KARTHIKEYAN, K., & REDDY, J. (2021). Performance study of solar photovoltaic cold storage system using phase change materials. *Materials Today: Proceedings*, *46*, 9623-9629. https://doi.org/10.1016/j.matpr.2020.07.116

SATHISHKUMAR, N., KUMAR, V. A., GOKULNATH, M., & RAJ, G. K. (2020). Performance analysis of palmitic acid coated PCM storage container. *Int. J. Res. Rev*, *7*(3). http://www.ijrrjournal.com/IJRR_Vol.7_Issue.3_March2020/Abstract_IJRR0067.html

SHARMA, S. D., KITANO, H., & SAGARA, K. (2004). Phase change materials for low temperature solar thermal applications. *Res. Rep. Fac. Eng. Mie Univ*, *29*(1), 31-64. https://www.eng.mie-u.ac.jp/research/activities/29/29_31.pdf

SORHOCAM.COM. "Hasat sonrası kayıplar", https://www.sorhocam.com/konu.asp?sid=1124&meyvevesebzelerin-muhafazasi.html. Son erişim tarihi: 26 Ekim 2020.

TARAKCIOĞLU, I. 1984. Tekstil Proses İşlemlerinde Enerji Tüketimleri ve Ekonomisi, Uludağ Üniversitesi. Tekstil Müh. Böl. Yayınları, 18. https://acikerisim.uludag.edu.tr/bitstream/11452/2596/1/284812.pdf.

TAO, Y., LI, X., & WU, B. (2008, October). An Effective PCM Based Environment Compensation Approach in Speech Processing for Mobile e-Learning Platform. In *2008 Third International Conference on Pervasive Computing and Applications* (Vol. 2, pp. 772-775). IEEE. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=4783713

TATSIDJODOUNG, P., LE PIERRÈS, N., & LUO, L. (2013). A review of potential materials for thermal energy storage in building applications. *Renewable and Sustainable Energy Reviews*, *18*, 327-349. https://doi.org/10.1016/j.rser.2012.10.025

TIGIST, M., WORKNEH, T. S., & WOLDETSADIK, K. (2013). Effects of variety on the quality of tomato stored under ambient conditions. *Journal of food science and technology*, *50*(3), 477-486. https://link.springer.com/article/10.1007/s13197-011-0378-0.

TUSIAD, 1998, "21. yy. Girerken Turkiye'nin Enerji Stratejisinin Degerlendirilmesi" TUSIAD-T/98-12/239.

UNDP, (2006). GEF Destek Programı (SPG), Küresel İklim Değişiklikleri için Yerel Çözümler ve SPG Yaklaşımı, TTGV., ART Tanıtım LTD. Şti. 8-12.

ÜÇGÜL, İ. (2009). Soğuk depolama için güneş enerjili ejektör soğutma sistemi uygulamasının termodinamik çevresel ve ekonomik analizleri. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi*, *15*(2), 269-277. https://dergipark.org.tr/en/download/article-file/190925

WU, W., TANG, H., MIAO, P., & ZHANG, H. (2015). Preparation and thermal properties of nano-organic composite phase change materials for cool storage in air-conditioning. *CIESC J*, *66*, 1208-1214. http://dx.doi.org/10.11949/j.issn.0438-1157.20141252

YANG, T., SUN, Q., WENNERSTEN, R., & CHENG, L. (2018). Review of phase change materials for cold thermal energy storage. *Journal of Engineering Thermophysics*, *39*(3), 567. file:///C:/Users/COMU/Downloads/Yang_2018_Review_of_Phase_Change_Materials_for%20(4).pdf

ZALBA, B., MARIN, J. M., CABEZA, L. F., & MEHLING, H. (2003). Review on thermal energy storage with phase change: materials, heat transfer analysis and applications. *Applied thermal engineering*, *23*(3), 251-283. https://doi.org/10.1016/S1359-4311(02)00192-8

ZARAJABAD, O. G., & AHMADI, R. (2018). Numerical investigation of different PCM volume on cold thermal energy storage system. *Journal of Energy Storage*, *17*, 515-524. https://doi.org/10.1016/j.est.2018.04.013

ZHANG, X., SHI, Q., LUO, L., FAN, Y., WANG, Q., & JIA, G. (2021). Research Progress on the Phase Change Materials for Cold Thermal Energy Storage. *Energies*, *14*(24), 8233. https://doi.org/10.3390/en14248233

ZHAO, Y., ZHANG, X., XU, X., & ZHANG, S. (2020). Development of composite phase change cold storage material and its application in vaccine cold storage equipment. *Journal of Energy Storage*, *30*, 101455. https://www.sciencedirect.com/science/article/pii/S2352152X20304564

ZUO, J., LI, W., & WENG, L. (2011). Thermal performance of caprylic acid/1-dodecanol eutectic mixture as phase change material (PCM). *Energy and Buildings*, *43*(1), 207-210. https://doi.org/10.1016/j.enbuild.2010.09.008