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Effect of Packaging Materials and Essential Oils on Quality and Storability of Jerusalem *Artichoke* Fresh Tubers

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ABSTRACT

Jerusalem artichoke has gained popularity as a new vegetable appearing in markets over the past few years. To improve the quality and storability of tubers, two types of packages (perforate high density polyethylene HDPE and polypropylene PP) and two kinds of essential oil (spearmint and black cumin oils comparing untreated, control) were examined on two varieties (Local cultivar and Fuseau) of Jerusalem artichoke stored at 4ºC and 90-95 % RH for 2, 4, 6, 8 and 10 months. Weight loss%, decay%, dry matter%, general appearance (GA), sprouting %, microbial load (total count and yeast & mold), total soluble solids, inulin, total and reducing sugars content were monitored periodically every 2 months during storage. Results showed that Local cultivar tubers were much better in all physical and chemical characters except inulin and total sugars content, Fuseau cultivar tubers were the better. Moreover, storage in the perforated PP package allows maintaining suppress weight loss % and decay %, and increasing dry matter %, reducing sugars content and GA tubers quality. Conversely, HDPE package recorded the least microbial load and sprouting% and the better inulin, total sugars, and TSS. Otherwise, treated tubers with spearmint and black cumin oils resulted in loss less weight by about 63%, decay % was zero for 4 months, reducing microbial load, decreased sprouting % by 72.09% and maintain a good GA quality compared with control. Generally, it is recommended with storage Local cultivar tubers after treated with black cumin oil and packaged in PP at 4ºC and 90-95 % RH which showed significantly reduce in weight loss by 16% and decay by 18% only as well as maintaining the good overall appearance and most physical and chemical properties for 10 months storage.

Keywords*:* Jerusalem artichoke, Cultivars, Packaging material, Spearmint oil, Black cumin oil, Storage, Quality, Inulin.

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INTRODUCTION

Jerusalem artichoke (*Helianthus tuberosus* L) called also sunroot, sunchoke or earth apple is a perennial of the Asteraceae Family (Compositae) that is grown as an annual. There are many cultivars and their selected depend upon the production location. It is originated from the North Central part of the USA, both above- and belowground parts of the plant are utilizable for various applications. For instance, tops for biomass and animal feed and tubers as a feedstock for food and non-food chemical production. Tubers are varying in color, shape, size, and surface topography (Kays & Nottingham, 2008).Nowadays Jerusalem artichoke is becoming an important crop for production of healthy foods (Danilcenko *et al.,* 2008).

This crop is privileged of the carbohydrate inulin rather than starch in its tubers. Inulin can promote immunity, prevent obesity as well as minimize blood cholesterol and heart disease also the risk of insulin-dependent diabetes mellitus (type 2) (Orafti, 2005). It is also used to produce a variety of products such as animal feed and bio-ethanol (Zaky, 2009). Recently, it has been recognized that this tuber promising biomass for bio-economy development, with a number of advantages over traditional crops such as low input cultivation, wide adaptation to climatic, high crop yield, soil conditions and strong resistance to diseases and pests. A variety of bioproducts can be derived from J. artichoke, including inulin, fructose, antioxidant, bioethanol and natural fungicides (Yang *et al*., 2015).

Some cultivars are much more influence to storage losses, but there are no reports on the effect of storage conditions on quality deterioration. These troubles in storage can result from the fact that tubers lack of a corky surface layer, similarly potatoes, which could reduce transpiration, but have a thin, easily damaged surface that permits rapid water loss (Saengthobpinit and Sajjaanantakul, 2005). Cholada *et al*., (2016) showed that high variation in genotype and genotype × year interactions (G × Y) were observed for inulin content and tuber yield and extensive evaluation in many years is necessary (Puttha *et al*., 2012).

Storage temperature is the most important factor for regulation the rate of associated physical and chemical processes in the tubers. However, cooling has long been recognized as a very important factor for keeping the quality (Spinardi and Ferrante, 2012). Evidence has been presented on jerusalem artichoke tubers by Attia and Alian, (2011) showed that higher storage temperature increased weight loss and decay as well as encouraged breakdown of total sugars and Inulin during storage and Artes *et al*., (2001) found that the head flowers of globe artichoke stored at 6 and 9ºC lost 1.3 and 2.9%, respectively while, those stored at 0ºC lost 0.8% after 16 days of storage but the heads stored at 17ºC could not be extended more than 10 days. Also, Danilcenko *et al*., (2008) found that JA tubers stored in 0 to 2°C and RH of 90 to 95% for can be kept several months. However, storage of harvested tubers usually caused high losses in quality, these results mainly by drying, rotting, sprouting and freezing.

Packaging materials are an important tool for cold storage to keep more good qualities for better marketing. Therefore, it was found that stored head flower of globe artichoke at 4ºC in polyethylene bags showed a lesser loss in weight, unmarketable and maximum general appearance comparing to unpackaged heads (Del-Nobile *et al*., 2009). Simon *et al*., (2008) found that cauliflower stored curds at 0ºC in polyvinyl chloride or polypropylene bags kept more total sugars and T.S.S. than unpacked ones. The use of selective film for prolonging the storability of tubers was studied. Packed Jerusalem artichoke tubers in polyethylene bags reduced weight loss and delayed tuber senescence compared with unpackaged during storage (El-Sharkawy, 1998).

Packaged fresh-cut vegetables for the retail market, the first step is determined surface area and product fill weight to a certain degree to achieve a market appeal. However, the respiration rate is also influenced by numerous factors, including storage temperature, cut size and vegetable types. Thus, selecting package films with suitable OTRs play an important role in developing MA packages for improved quality and shelf-life of fresh-cut products (kim *et al*., 2004). J. artichoke tubers are difficult to store outside the soil because of the rapid onset of several phytopathogenic fungi, causing rust, southern blight, and tuber rot diseases that can limit its yield production. Under storage conditions, approximately 20 pathogens causing storage rots have been isolated from JA tubers, which vary in their disease potentiality and economic significance (Kays and Nottingham, 2008). Packaged jerusalem artichoke tubers in such a way of the selective film for prolonging the storability in polyethylene bags reduced weight loss and delayed tubers senescence compared with unpackaged during storage (Danilcenko *et al*., 2008).

Antimicrobial activity of spearmint (*Mentha spicata*) oil and its major components (cis-carveol and carvone) was strongly affected indicating an appreciable antimicrobial potential of spearmint oil. Spearmint oil was possessed antibacterial, antifungal, antiviral, insecticidal and antioxidant properties (Hussain *et al*., 2010). Black cumin oil has been shown to demonstrate antibacterial, antifungal and antioxidant activities (Hassanien *et al*., 2013). Spearmint contains bioactive compounds able to inhibit the growth of the pathogen storage environments as well as improve the quality parameters of JA tubers and its storability (Ghoneem *et al*., 2016). Carvone is a member of a terpenoids family, a component of the essential oils from spearmint. This compound has been used for postharvest on tubers. It protects against fungal storage diseases as well as, acting as an anti-sprouting agent (Szczerbanik *et al*., 2007). Ahmed *et al*. (2013) found that the application of mint essential oil had improved the storability of two onion cultivars in the cold store by decreasing the bulb sprouting and lowering the loss of fresh weight. It had no effect on dry matter and T.S.S. In the traditional store, it had no effect on the storability of both cultivars. Monthly thermal fogging with mint oil was inhibited sprouting in eight potato cultivars during six months storage. 73% monoterpene R-carvone was the main component of mint oil analysis (Teper-Bamnolker *et al*., 2010).

Although the consumption of fresh jerusalem artichoke tubers has increased in the past decade, little information exists on its quality maintenance. However, simple methods are not costly for storage of jerusalem artichoke tubers are applied, for example regular storehouses or over wintering tubers in an open field but technologically risky method, like over wintering a colder climate may occur some freezing injuries, and also it is impossible to pick up the tubers from the soil during the winter in addition rapid onset of several phyto pathogenic. For that, the objectives of the present work were to study the effect of packaging materials especially for the retail market to achieve a market appeal and essential oils on the quality and storability on two varieties of jerusalem artichoke fresh tubers during cold stores at 4°C and RH of 90 to 95% for several months.

MATERIALS AND METHODS

The experiment was carried out during two successive seasons, 2015 and 2016 on two varieties of fresh jerusalem artichoke (JA) tubers at Laboratory of Sakha Horticultural Research Station, Kafr El- Sheikh Governorate, Egypt, to study the effect of packaging materials, essential oil, and two varieties of jerusalem artichoke, to improve storability of these fresh tubers. Fresh tubers of J. artichoke (Local and Fuseau cultivars) were commonly cultivated at the Experimental Farm of Sakha Horticultural Research Station (31-07' N Latitude, 30-57'E Longitude). Tubers were planted on April 16th and harvested on November 16th in the two seasons, then transported immediately to the laboratory.

Treatments included the following:

1. Varieties,	1- Local Variety 2- Fuseau variety
2. Packaging materials	1-Polypropylene (PP) 2- High-density polyethylene (HDPE)
3. Essential oils	1- Spearmint oil 2- Black cumin oil 3- control (untreated)
4. Storage period at 4ºC and RH at 90 to 95%	1- two months 2- four months 3- six months 4- eight months 5- ten months

Essential oils source:

Pure-grade (without synthetic chemicals and/or non-natural components, 99-100% pure) of spearmint (*Mentha spicata* L) black cumin (*Nigella sativa* L) essential oils were purchased from Assiut Organic Company For Oils Extraction, Egypt. These essential oils were stored in dark bottles at 4ºC until used in the experiments.

Main components of essential oils:

The main components of spearmint (*Mentha spicata* L) were carvone (51.7%) and cis-carveol (24.3%), followed by limonene (5.3%), 1,8 cineol (4.0%), cis-dihydrocarvone (2.2%), carvyl acetate (2.1%) and cis-sabinene hydrate (1.0%) (Hussain *et al*., 2010). The major components in black cumin (*Nigella sativa* L) essential oils were thymoquinone (37.6%) followed by p-cymene (31.2%), αthujene (5.6%), thymohydroquinone (3.4%), and longifolene (2.0%) whereas the oleoresins extracted in different solvents contain linoleic acid as a major component (Singh *et al* ., 2014).

Packaging sources:

Polypropylene (PP thickness 55u) was obtained from the Islamic Company for Packages in October 6th City, Giza, Egypt, whereas, high density polyethylene (HDPE thickness 30u) was obtained from Arabic Medical Packaging Company (flexpack) Cairo, Egypt.

Preparation of fresh tubers for storage:

Tubers were sorted out and all the defected tubers were discarded, and then washed several times with tap water to get rid of contaminants. Spearmint and black cumin essential oils were performed by dissolving the requisite amounts of each oil (2 ml/l) in 23 ml of 0.05 % tween-80 then mixed with 975 ml of distilled water. For the surface application of coating treatments, after washing and air-drying, these tubers were subjected to different postharvest coating treatments with spearmint and black cumin essential oils by dipping them for 5 minutes and air dried at room temperature (Hadizadeh *et al*., 2009). Another set of un-treated tubers was dipping in distilled water and served as control treatment. Some tubers were packed in perforated high density polyethylene (HDPE) and perforated polypropylene (PP) (10% from the area of the package 80 holes/package with 0.5mm in diameter), the sealed package size was 20 x 40cm, another set of un-treated tubers was unlined and served as control treatment, weighted 400g for each package then stored at 4ºC and 90-95 % RH for 2, 4, 6, 8 and 10 months, respectively. Samples were withdrawn every 2 months for evaluation the following characteristics before and after storage.

Photo 1. Dipping in essential oil

Physiochemical and biochemical changes: All physical and chemical characteristics were recorded at harvesting date (zero-day) and after 2, 4, 6, 8 and10 months.

1. Weight loss %: The difference between the initial weight of the tubers and that recorded at the date of sampling was translated as weight loss percentage and calculated as follow:

$$\textbf{Weight loss \%} = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \textbf{x100}$$

2. Dry matter %: The average of dry matter percentage was calculated as follow:

$$\textbf{Dry matter (\%)} = \frac{\text{Dry weight}}{\text{Fresh weight}} \textbf{x100}$$

3. Decay % (Unmarketable percentage): The percentage of disordered tubers included all of the spoiled tubers resulted from desiccation, rotting, sprouting, and freezing were assessed and the defects were calculated as follows:

$$\textbf{Decay \%} = \frac{\text{Weight of decay}}{\text{The initial weight at the beginning of storage}} \textbf{x100}$$

4. General appearance (GA): It was determined according to the scale of scoring system as explained by Able *et al*.,(2002) They were: 9: excellent, 7: good, 5: fair, 3: poor and 1: unsuitable. This scale depends on the morphological defects such as loss of compactness, shriveling and presence of physiological and pathological defects.

5. Microbial enumeration: The microbial contents were determined according to methods described in the DIFCO manual (DIFCO, 1977). Acidified potato dextrose agar and nutrient agar were used to enumerate yeast & mold and total microbial counts, respectively. Three plates of these cultures were enumerated and expressed as colony forming units per gram sample (CFU/ g)

6- Sprouting %: All sprouted tubers were counted at 2, 4, 6, and 8 and 10 months of storage, sprouting percentage was then calculated according to Ibrahim, *et al*.., (2017).

$$\textbf{Sprouting \%} = \frac{\text{Number of sprouted tubers}}{\text{Total number of tubers}} \textbf{x100}$$

7. Total Soluble Solids (TSS) %: The total soluble solids content of the fresh tubers was measured using a hand refractometer according to the method outlined in A.O.A.C. (2005).

8. Total and Reducing sugars: It was determined after 4 and 10 months from storage as g/100g dry weight, as reported by Dubois *et al.* (1956).

9. Inulin concentration: The inulin content was determined after 4 and 10 months from storage according to Winton and Winton, (1958)

Statistical analysis: Data obtained from experimental treatments were subjected to the analysis of variance using the Costat Statistical and treatments (Co-Stat Statistical Software, 2003), means were compared using L.S.D. range test at 5 % level according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

1. Physiochemical changes:

Effect of storage period:

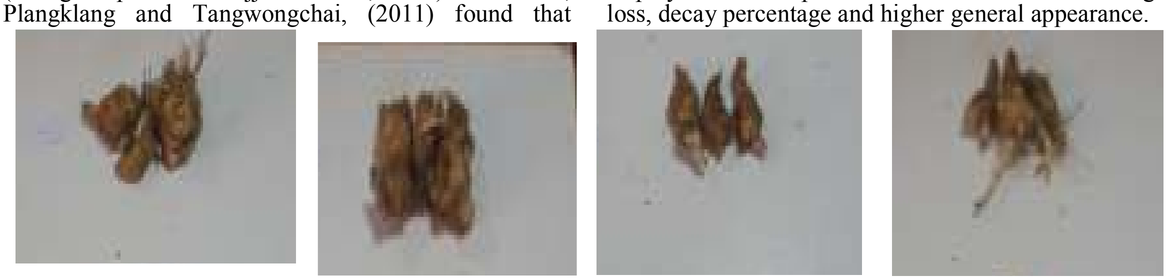
It is cleared that the period of storage, cultivars, packaging materials and oil treatments had highly significant effects on the percentage of weight loss, dry matter and decay of JA stored in 4˚C (Table, 1). A continuous gradual loss happened in tubers weight reached to 28% with the prolonged of the storage periods to 10 months in all treatments for the two seasons. Interestingly, it was noted that there was a slight increase in decay % from 0 to 6 months, and also a sharp increase in the following 4 months (from 6 to 10 months). Dry matter of J. artichoke tubers increased by increasing storage periods even 6 months and vice-versa until the end of storage period in the two seasons. This may be attributed to, tubers lack a corky surface layer which, could decrease transpiration. It have a thin, easily destroy surface that permits rapid water loss through transpiration and loss in dry matter content through respiration but low temperature will delay respiration and other metabolic activities, moisture loss, aging, spoilage, flavor changes and undesirable growth (Haggag *et al*., 2017 and Danilcenko *et al*., 2008). Similarly, Kader (2011) found that during cold storage at 2˚C, there was continuous increasing in weight loss, more appearance of unmarketable tubers and reduction the general appearance with extended the storage periods. Jerusalem artichoke tubers are contained high water content which is subjected to desiccation that leads to wilting and shriveling during storage (photo 2).

Effect of cultivars:

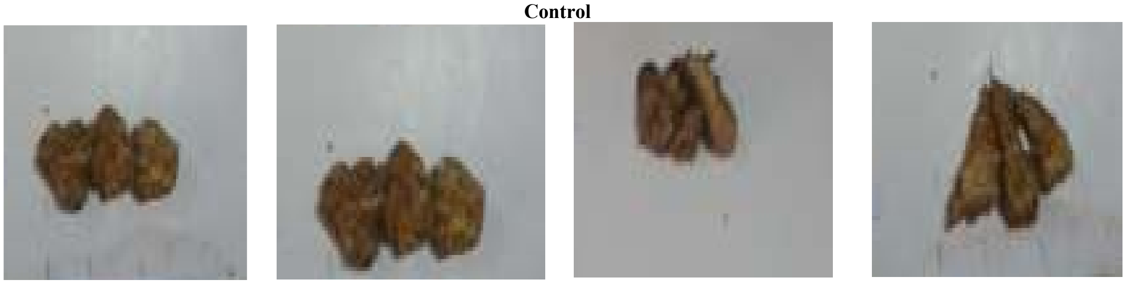
There were highly significant differences in weight loss, dry matter and decay % of J. artichoke tubers among cultivars different (Table, 1). The local cultivar was much better in lessening weight loss, dry matter, and decay % than Fuseau tubers. On the other hand, after harvest, immediately dry matter % was 23.61 and 22.64% in the first season and 23.90 and 23.21% in the second season, for Local cultivar and Fuseau cultivars, respectively (Fig, 2). These may be attributed to the two cultivars have a different branchy shape and leak even more easily than the other for that, Fuseau tubers considerably higher transpiration (Saengthobpinit and Sajjaanantakul, 2005). Otherwise, Plangklang and Tangwongchai, (2011) found that temperature and storage period did not influence on moisture content in both varieties of JA tubers.

Effect of packaging material:

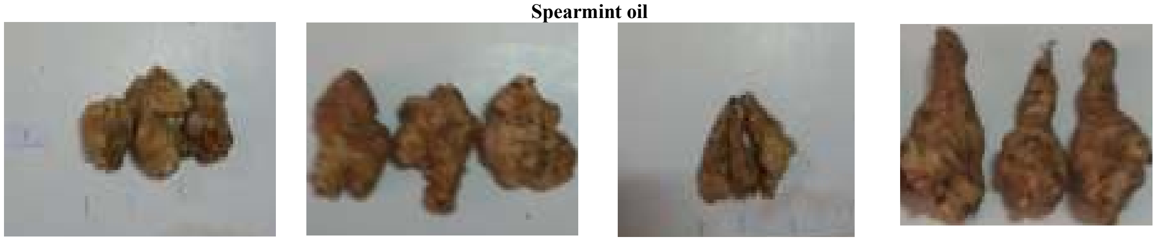
The different packaging materials resulted in reducing weight loss, decay% and maintenance dry matter % in both seasons. Evidence shows that tubers stored in perforated PP at 4˚C loss less weight and decay % and increase dry matter % compared with those stored in the perforated HDPE in the two stores seasons. These results may be due to differences in characteristics of films used such as permeability and thickness (Cefola, *et al.,* 2012*)*. Likely, Haggag *et al*., (2017) and Danilcenko, *et al.*, (2008) reported that the tubers or heads stored in plastic boxes either lined with perforated PP or unlined under 0˚C or 5˚C and 95% RH display that lined plastic boxes achieved lower weight loss, decay percentage and higher general appearance.



Control



Spearmint oil



Black cumin oil

PE **PP** **PE** **PP**

Local cultivar **Fuseau**

Photo 2. Tubers after 6 months of storage at 4ºC and 90-95 % RH.

Effect of essential oils:

The resulted data of the oil treatments proved that the spearmint and black cumin oil exhibited loss less weight as compared with those nontreated (control), this lessening percentage reached to approximately half of the control. Soaking JA tubers in black cumin oil were the most effective in minimizing the loss in weight by 63.99 and 62.94 % for the two stored seasons, respectively comparing untreated one. On the other hand, black cumin oil reduced decay % as compared with control and spearmint treatments. Irrespective of storage conditions, dry matter was bigger in tubers without soaking oil (control) than in tubers soaking in spearmint oil followed by tubers soaking in black cumin oil in the two seasons. The reason could be due to plant essential oils constitute are a rich source of bioactive chemicals such as phenols, tannins, flavonoids, quinones, saponins, alkaloids, sterols and saponins. Moreover, these oils can also maintain the biochemical constituents of the tubers during storage and they can biodegradable to nontoxic products (Combrinck *et al*., 2011).

Table 1. Effect of storage periods, cultivars, packaging materials and oil treatments on weight loss, dry matter and decay % of Jerusalem artichoke fresh tubers during 2015 and 2016 seasons.

Characteristics	Weight Loss (%)	Dry matter (%)	Decay (%)	Weight Loss (%)	Dry matter (%)	Decay (%)
Treatment		1[st] Season			2[nd] season	
storage period (month)						
2 month	14.64	22.625	7.125	15.315	22.755	7.892
4 month	20.33	23.248	16.113	21.176	23.350	16.879
6 month	23.59	23.626	22.054	24.340	23.729	22.821
8 month	25.99	23.366	28.633	26.660	23.469	29.40
10 month	27.39	23.177	35.442	28.069	23.280	36.208
Sig	**	**	**	**	**	**
L S D (0.05)	0.131	0.1141	0.5402	0.2104	0.1197	0.540
Cultivars (v)						
Local	21.541	23.404	24.635	22.284	23.506	25.402
Fuseau	23.231	23.014	24.987	23.940	23.127	25.754
Sig	**	**	*	**	**	*
L S D (0.05)	0.0828	0.0722	0.2205	0.1331	0.0708	0.2205
packaging materials (p)						
PP	21.80	23.392	23.989	22.482	23.494	24.755
HDPE	22.97	23.026	25.508	23.742	23.139	26.274
Sig	**	**	**	**	**	**
L S D (0.05)	0.0828	0.0722	0.2303	0.1331	0.0708	0.2303
Oil treatment (O)						
Control	38.248	24.01	25.561	38.985	24.113	26.327
Spearmint	15.136	22.313	25.357	15.903	22.426	26.124
Black cumin	13.773	23.303	23.905	14.447	23.410	24.671
Sig	**	**	**	**	**	**
L S D (0.05)	0.1014	0.0884	0.2887	0.1630	0.0867	0.2887
Interaction between treatments						
s*v	**	**	*	**	**	*
s*p	**	ns	**	**	ns	**
s*O	**	ns	**	**	ns	**
v*p	**	ns	ns	**	ns	ns
v*O	**	ns	ns	**	ns	ns
p*O	**	**	**	**	**	**
s*v*p	**	ns	ns	**	ns	ns
s*p*O	*	ns	ns	*	ns	ns
v*p*O	*	ns	*	ns	ns	*
s*v*O	*	ns	*	ns	ns	*
s*v*p*O	*	ns	**	*	ns	**

***, **, *** and NS: significant at p ≤ 0.05, 0.01, 0.001or not significant, respectively. Means separated at P≤ 0.05, LSD test.**

The interaction effects:

Local cultivar tubers soaking in black cumin oil and stored in perforated PP package kept the lowest loss in weight % for the longest storage periods (Fig. 1 and Photo 2). It has been demonstrated that at the end of 10 months storage, weight losses of Local cultivar tubers soaking in black cumin oil and stored in PP package were lower approximately 60.75 % than non-treated tubers (control). Local cultivar tubers soaked in black cumin oil and packed in perforated PP package for 2 months recorded the less weight loss%. Decay% in the two cultivars was recorded zero% for 4months in tubers stored in perforated PP either soaking in spearmint or black cumin oil compared with the control (16.54 and 14.45%)for Fuseau and Local cultivar, respectively. Otherwise, black cumin oil is superior than spearmint oil after 4 months. Therefore, we could storage in the perforated PP, soaking in black cumin oil for 8 months by 18.20 % decay, which allows maintaining Jerusalem artichoke quality. Similar results were reported by Kim *et al.*, (2004) and El-Awady and Ghoneem (2011).

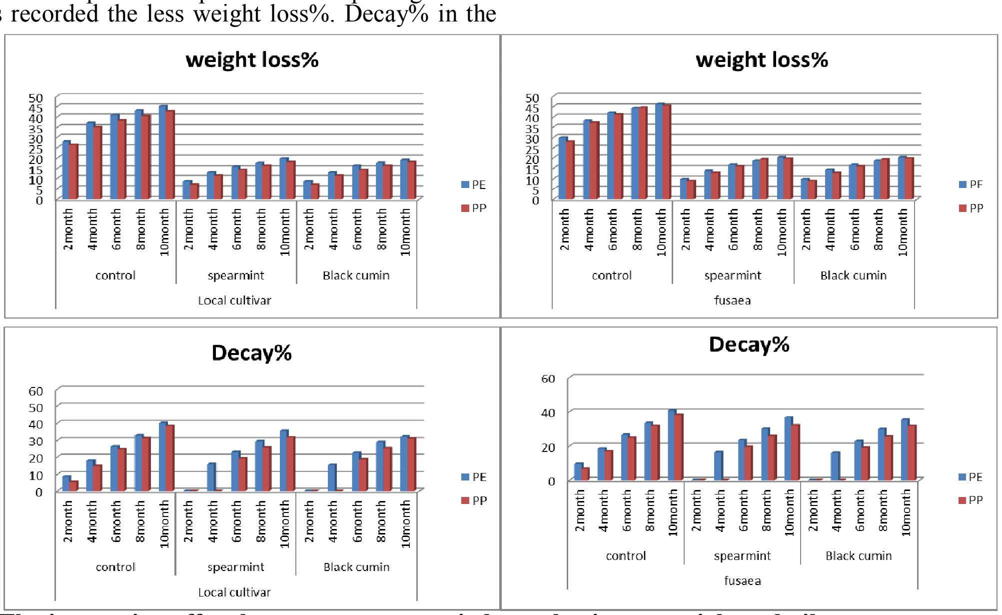


Fig 1. The interaction effect between storage periods, packaging materials and oil treatments on weight loss and decay % of the two cultivars for Jerusalem artichoke fresh tubers (mean of the two seasons).

2. Sensory attributes and microbial load:

General appearance and sprouting % are important factors influencing the marketability of Jerusalem artichoke tubers; they were evaluated to determine whether the tubers were acceptable at the end of storage. Poor GA in produce packages is often an indicator of active the microbial load which, many fungi can grow at low temperatures and cause fundamental destroys, especially when storage prolonged for long period. It can be seen that the method of storage significantly influenced on quality of tubers, including weight loss for 45% after 10 months. This loss showed from transpiration mainly and caused drying of tubers, which could be detected even visually. Results on the sensory quality attributes of microbial load, GA, and sprouting % are shown in Table 2 and photo 3.

Effect of storage period:

Because of the tubers lack of a corky surface layer may be more vulnerable to microbial attachment and growth for that, a slight gradual increase of total account and Y&M populations on JA tubers from zero-day to 10 months reached to 22.61 and 30.67 CFU /g and 23.72 and 32.09 CFU /g of both total account and Y&M in the two seasons, respectively (Table 2). In addition, there was a gradually quality loss among all treatments from zero-day to 10 months. Starting 8 months, tiny black spots and decrease in crispness or turgidity were observed on some tubers of JA, resulting in reduced general appearance scores (good even 4 months and fair even 8 months). At the end of storage, the overall general appearance scores of the tubers in all treatments had declined to 3.13 and 3.05 in the two seasons, respectively which were above the acceptable level. This may be attributed to, for a long term of storage microbiological, enzymatic, biochemical and various changes of J. artichoke tubers which may lead to tuber damage. The loss of the stored plant reserves during respiration, hastening senescence, increase the loss of visual quality, soluble dry weight loss and reduction the nutritional value of the plant (Sams,1999). During storage, regardless of the microbial load or GA, there was a gradual increase in sprouting % starting from 6 months of storage 3.57 and 3.97% for the two seasons, respectively to 16.15 and 17.94% for the two seasons, respectively at the end of storage (Photo 3). Increasing sprouting% may be due to accelerate respiration rate with extended storage period and other metabolic activities such as carbohydrate reserves degraded to sugars and structural rapidly developing sprout tissues, sprouts serves as a powerful sink for the mobilized sugars (El-Awady and Ghoneem, 2011).

Black cumin oil

PE PP PE PP

Local cultivar Fuseau

Photo 3. Tubers after 10 months of storage at 4ºC and 90-95 %RH

Effect of cultivars:

Cultivars also differed significantly in microbial load, general appearance and sprouting % in the two seasons. Local cultivar tubers recorded less microbial load and sprouting %. Furthermore, a highly general appearance comparing with Fuseau tubers. Moreover, immediately after harvest, the initial microbial load of Local cultivar tubers was relatively low (13.60 and14.61 CFU /g for TA microbial and15.77 and15.82 CFU /g for Y&M) and high general appearance (8.81 and 8.58 in the two seasons, respectively) comparing with Fuseau tubers (Fig. 2). A similar result was recorded by plangklang and Tangwongchai, (2011) who found that firmness of HEL65 did not change during storage but JA89 significantly decreased after 2 and 3 weeks of storage at 5 and 10˚C.

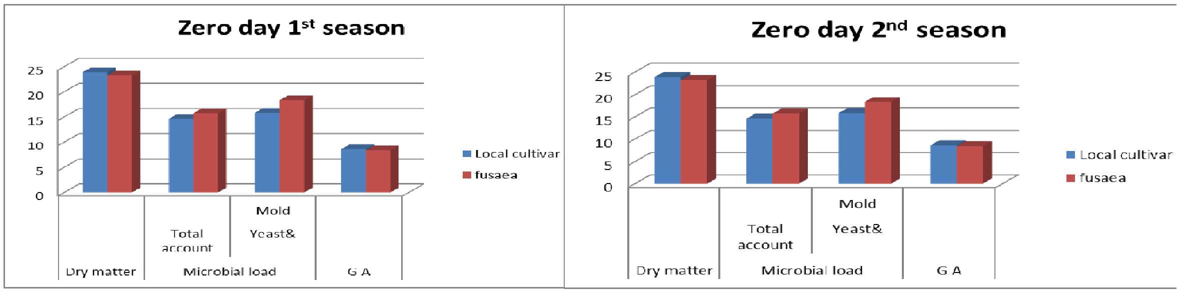


Fig 2. Physical and chemical properties of the two cultivars of Jerusalem artichoke fresh tubers at harvesting date for the two seasons.

Effect of packaging material:

There was a highly significant difference in the growth of total account and Y&M among PP and HDPE package (Table 2). Overall, tubers packaged in PP film maintained relatively better general appearance (Photo 4), HDPE gave the lowest microbial load (total account and Y&M) for that, there was highly significant difference in the growth of total account and Y&M among PP and HDPE package, suggesting that different packaging materials influenced the overall growth of total account and Y&M of tubers under storage conditions. Moreover, tubers packaged in PP showed high values in sprouting% comparing with tubers packaged in HDPE. These results may be assigned to more decrease in respiration rate combined with reduce ethylene production that led to better marketable and general appearance (Alexopoulos *et al*., 2003). Also, these results may be regarding to the (MA) modified atmosphere package that decreased respiration rate which depends on the commodity, variety, beside thickness and permeability of film used (Cefola, *et al.,* 2012). A slight increase and peaked on 6 months, followed by rapidly initially. Likely, Xiao *et al.* (2014) observed that storage temperature significantly influenced on package atmosphere, maintaining product quality and shelf life of radish microgreens. So, preserve the suitable environment around the plant during the storage.

Photo 4. Effect of package materials on general appearance of JA tubers at 25ºC after 10 days

Effect of essential oils:

Beneficial effects of essential oil treatments on microbial load, GA, and sprouting % were obtained. As well as, black cumin oil recorded the major decrease in microbial load by 14.09 and 12.18 % and 13.37 and 9.45 % for a total account and Y&M in the two seasons, respectively compared to the control. These results may be due to the antifungal activity of the essential oil against various pathogenic fungi. Components, limonene and carvone have a highly similarity for cell membranes, as loss of bacterial membrane integrity that disturbs the membrane barrier function by carvone. While, limonene described as damaging bacterial cell morphology and changing composition of membrane fatty acid (Espina *et al.,* 2011). Black cumin oil decreased sprouting % by 72.09 and 71.45% for the two seasons, respectively. Among GA quality of tubers, black cumin oil led to a good GA as comparing to spearmint and untreated one. Our observations are consistent with the results of a research by Gomez-Castillo *et al., (*2013) who found that the active compounds, limonene, cymene, carvone, and cymene, in spearmint and black cumin oil are known to suppress tubers sprouting by the reduce of mitochondrial respiration, decreasing carbohydrate and degradation sugar. Carvone may play a more specific role in the sprouting growth, by the inhibition of the key enzyme in the mevalonate pathway, which is the main pathway of gibberellin biosynthesis. Gniewosz *et al.,* (2013) observed that at the end of storage, treated samples with pullulan–caraway oil coating maintained better visual acceptability than control samples. Ahmed *et al.,* (2013) recorded that mint oil regarding sprout inhibition in onion bulbs.

Table 2. **Effect of storage periods, cultivars, packaging materials and oil treatments on Microbial load (CFU/ g), General Appearance, Sprouting % of Jerusalem artichoke fresh tubers during 2015 and 2016 seasons.**

Characteristic / Treatment	Microbial load (CFU/ g)		General Appearance	Sprouting (%)	Microbial load(CFU/ g)		General Appearance	Sprouting (%)
	Total account	Yeast& Mold			Total account	Yeast& Mold		
	1st Season				2nd season			
storage time (s)								
2 month	15.382	17.669	8.521	0.00	16.503	19.089	8.351	0.00
4 month	17.462	20.987	7.334	0.00	18.732	22.41	7.166	0.00
6 month	19.944	24.142	5.353	3.572	21.059	25.571	5.091	3.955
8 month	21.233	27.345	4.375	6.242	22.344	28.779	4.205	6.961
10 month	22.607	30.669	3.132	16.15	23.723	32.089	3.050	17.942
Sig	**	**	**	**	**	**	**	**
L S D (0.05)	0.630	0.630	0.100	0.368	0.469	0.469	0.100	0.474
Cultivars (v)								
Local cultivar	19.088	23.858	5.860	4.861	20.177	25.289	5.748	5.269
Fuseau	19.635	24.466	5.626	5.524	20.768	25.886	5.397	6.274
Sig	**	**	**	**	**	**	**	**
L S D (0.05)	0.398	0.398	0.063	0.233	0.297	0.297	0.063	0.300
packaging (p)								
PP	20.981	25.658	5.885	5.973	22.077	27.084	5.702	6.727
HDPE	17.742	22.667	5.600	4.412	18.867	24.092	5.443	4.816
Sig	**	**	**	**	**	**	**	**
L S D (0.05)	0.398	0.398	0.063	0.233	0.297	0.297	0.063	0.300
Oil (o)								
Control	21.129	26.049	5.443	9.185	22.239	27.477	5.280	10.08
Spearmint	18.804	23.560	5.738	3.830	19.913	24.998	5.576	4.357
Black cumin	18.151	22.877	6.047	2.563	19.265	24.88	5.861	2.878
Sig	**	**	**	**	**	**	**	**
L S D (0.05)	0.4881	0.488	0.077	0.155	0.364	0.364	0.077	0.367
Interaction								
s*v	ns	ns	ns	**	ns	ns	*	**
s*p	ns	ns	*	**	ns	ns	**	**
s*O	ns	ns	**	**	ns	ns	**	**
v*p	ns	ns	ns	*	ns	ns	ns	*
v*O	ns	ns	ns	*	ns	ns	*	*
p*O	*	*	*	**	*	*	**	**
s*v*p	ns	ns	ns	*	ns	ns	ns	*
s*p*O	ns	ns	ns	**	ns	ns	*	**
v*p*O	ns	ns	ns	*	ns	ns	*	*
s*v*O	ns	ns	ns	**	ns	ns	*	**
s*v*p*O	ns	ns	ns	**	ns	ns	*	**

***, **, *** and NS: significant at p ≤ 0.05, 0.01, 0.001or not significant, respectively. Means separated at P≤ 0.05, LSD test.**

Interaction effects:

These results confirmed the contribution of essential oil and package on maintaining the quality and prolonging the shelf life GA of JA variety tubers (Fig 3). Among all treatments, Local cultivar tubers treated with essential oils, whether spearmint or black cumin packaging [n perforate HDPE did not observe any sprouting % until 8 months comparing the non-treated oil while, packaging perforated PP in the same condition sprouting starting after 6 months. This might be related to these essential oils are constituted by compounds, like phenolic compounds, with an antioxidant and antimicrobial activity that minimized or eliminated the presence of microorganisms and/or reduced the phenomenon of lipid oxidation inside some package more than the other. Therefore, they can reduce or replace the use of synthetic additives in the package. For this reason, some patents have been achieved due to the positive result of EOs incorporation in the package. The encapsulation of aromatic compounds of EO within a plastic film, created to protect and preserve horticulture products and foods against insects (Suppakul, *et al*., 2003). Similar results of investigations, Gniewosz *et al.*, (2013) showed that Pullulan films incorporated with caraway oil showed the maximum zone of inhibition against yeast. Furthermore, carrots treated with pullulan coating enriched with oil presented smaller microbial growth of *S. aureus*, *A. niger*, and *S. cerevisiae* throughout storage compared to the uncoated carrots as well as extending shelf-life of the vegetables. Similarly, Ahmed *et al*., (2013) on onion showed that mint oil treatment of onion bulbs showed a significant effect on sprout inhibition aspect of storability of Texas Early Yellow Grano in cold store but not on Baftaim. Takala *et al*., (2013) and Santos *et al*., (2017) recorded the same trend.

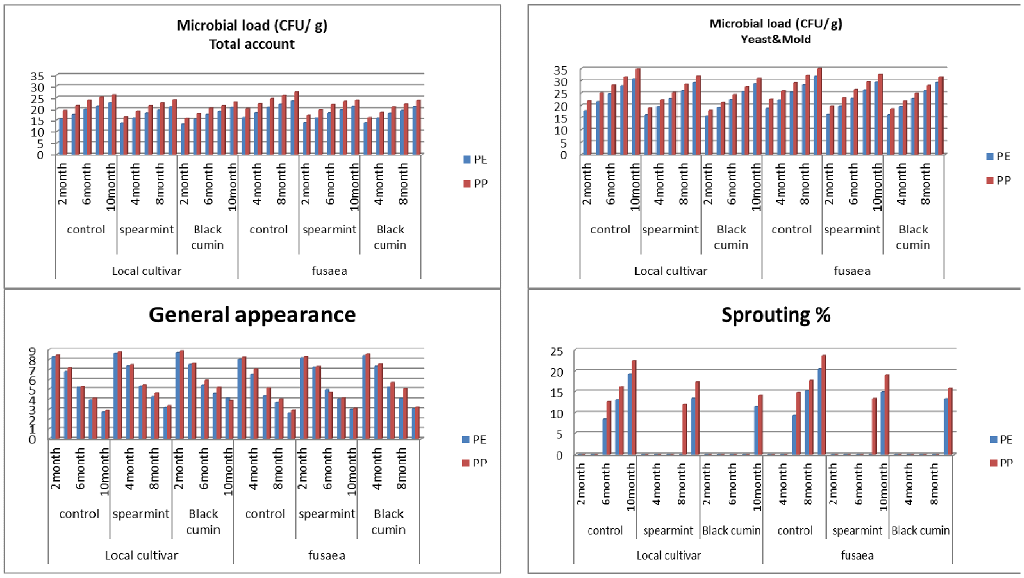


Fig 3. The interaction effect between storage periods, packaging materials and oil treatments on microbial load (CFU/ g), general appearance and sprouting % for the two cultivars of jerusalem artichoke fresh tubers (means of the two seasons).

3. Chemical composition changes:

Effect of storage period:

There was a progressive decrease in the inulin and TSS content in all the tested factors during the first 2 months of storage after which a drop happened till the last 8th month of storage (Table 3). TSS content in Jerusalem artichoke tubers depended upon storage period. The biggest loss of TSS was recorded after 10 months storage. Carbohydrates are the main chemical compounds recorded in tubers. Interestingly, it was noticed that a general increases in total and reducing sugars contents with the elongation of the storage period in all the treatments till 4 months which was followed by decreases till the last storage period at 10 months. Irrespective of storage conditions, the lowest total sugars and sucrose content were found in tubers stored for four months. After four months of storage, when the content of reducing and total sugars decreased noticeably, tubers expert stress and then adapted. During storage, the physiological processes continued and respiration rate was decreased, so the degradation of reducing and total sugars was irregular in that conditions. The structure of carbohydrates depends upon many factors, such as the plant source, the maturity, the climate, growing conditions, and storage time (Danilcenko, *et al.,* 2008).

Effect of cultivars:

Some cultivars are much more susceptible to storage losses than the others as well as, there were significant differences between the two cultivars in some chemical compositions as shown in (Table 3). After harvest immediately, TSS content was 24.76 and 24.47% in the first season and 25.04 and 24.86% in the second season, for Local cultivar and Fuseau cultivars, respectively (Fig 4). Results indicated that immediately after harvest Local cultivar recorded the highest TSS and reduce sugar content while Fuseau cultivar showed the high inulin and total sugar content in the two seasons.Otherwise, after 10 months storage, the highest loss of TSS (3.83%) was found for Fuseau tubers. The same result was recorded by Plangklang and Tangwongchai, (2011) showed that TSS in HEL65 variety slightly increased but rapidly decreased in variety JA89 after 2 weeks storage.

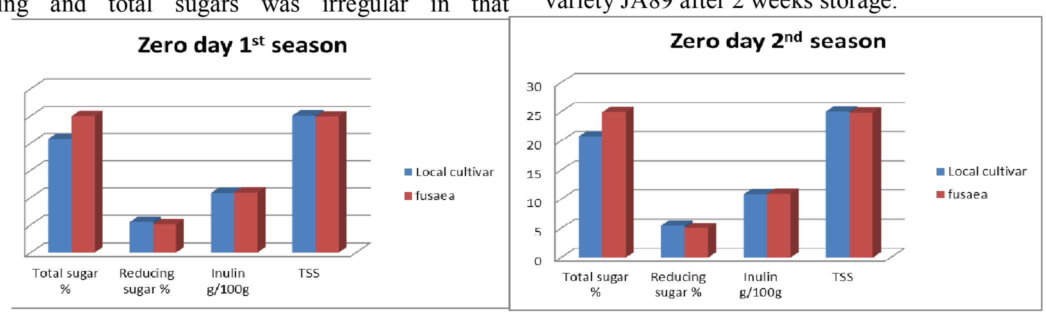


Fig 4. Chemical properties of the two cultivars of Jerusalem artichoke fresh tubers at harvesting date for the two seasons.

Effect of packaging material:

Studying the view of the obtained data (Table 3) showed that package materials differed significantly in affecting some chemical compositions of the tubers. Jerusalem artichoke tubers packaged in HDPE had the high inulin, TSS and reducing sugar content while; tubers packaged in PP had more total sugars than those stored in the HDPE package in the two seasons. The physiological processes intensity which, take place in PP package are greater, so the reduction of total sugars content in tubers is greater, too. Therefore, active exploitation of reducing sugars in cells stimulates the aging of tubers (Danilcenko *et al.,* 2008). Due to water losses, the highest content of reducing sugars was found in tubers kept in HDPE package compared with storage tubers in PP package. HDPE package is a good method for reducing their quality degradation and keeping high nutritive value. Similarly, Haggag *et al*., (2017) and Danilcenko, *et al.*, (2008) found that plastic boxes either lined with perforated polypropylene or unlined at 0˚C or 5˚C and 95% RH exhibited that lined plastic boxes existed kept TSS concentrations, total sugars and inulin and lower respiration rate comparatively to those heads or tubers stored in the unlined ones.

Effect of essential oils:

Soaking JA fresh tubers in essential oils recorded highly significant effects on chemical components as compared to (control). Treated tubers with spearmint oil showed the highest total and reduce sugar content. On the other hand, treated tubers with black cumin led to the high inulin content and TSS in the two seasons. These results may be due to the main constituents (antioxidants and monoterpenes) of the oils resorted to suppressing the activity of carbohydrates and protein breakdown associated with the enzymatic system as well as energy metabolism enzyme and respiration (Davies, 1990). This could be attributed to inhibitors of enzyme processes which could change this property. The presence of an aromatic nucleus and a phenolic OH group that is known to be reactive and can form a hydrogen bonds with-SH group in the active sites of target enzymes, resulting in deactivation of enzymes in fungi (Alma *et al.,* 2007).

Table 3. Effect of storage periods, cultivars, packaging materials and oil treatments on inulin, total and reducing sugar% and TSS% of Jerusalem artichoke fresh tubers during 2015 and 2016 seasons.

Characteristics	Inulin (g/100g)	Total sugar (%)	Reducing sugar (%)	TSS (%)	Inulin (g/100g)	Total sugar) (%	Reducing sugar (%)	TSS (%)
Treatment	**2014/2015 seasons**				**2015/2016 seasons**			
storage time (s)								
2 month	-	-	-	24.581	-	-	-	24.860
4month	7.498	16.895	5.772	24.343	7.968	17.442	6.165	24.593
6month	-	-	-	24.128	-	-	-	24.344
8month	-	-	-	23.269	-	-	-	23.477
10	6.547	17.072	8.424	22.485	7.017	17.619	8.817	22.721
Sig	**	Ns	**	**	**	Ns	**	**
L S D (0.05)	0.102	0.545	0.403	0.1580	0.102	0.960	0.558	0.1595
Cultivars, (v)								
Local cultiver	6.945	15.519	7.431	23.840	7.415	16.066	7.825	24.089
Fuseau	7.099	18.448	6.764	23.682	7.570	18.995	7.158	23.909
Sig	*	**	**	**	*	**	*	**
L S D (0.05)	0.102	0.545	0.403	0.0999	0.102	0.960	0.558	0.1009
packaging (p)								
PP	6.841	15.948	7.355	23.571	7.311	16.495	7.749	23.818
LDPE	7.204	18.019	6.840	23.951	7.674	18.566	7.233	24.179
Sig	**	**	*	**	**	**	Ns	**
L S D (0.05)	0.102	0.545	0.403	0.0999	0.102	0.960	0.558	0.101
Oil (o)								
control	6.660	14.907	6.929	23.503	7.130	15.454	7.323	23.764
spearmint	7.127	18.404	7.549	23.685	7.597	18.950	7.942	23.909
black cumin	7.280	17.636	6.815	24.095	7.750	18.186	7.208	24.323
Sig	**	**	**	**	**	**	Ns	**
L S D (0.05)	0.125	0.668	0.494	0.1224	0.125	1.175	0.685	0.1236
Interaction								
s*v	**	ns	**	ns	**	ns	**	ns
s*p	**	ns	ns	ns	**	ns	ns	ns
s*o	**	*	**	ns	**	ns	*	ns
v*p	**	ns	*	*	**	ns	ns	*
v*o	**	**	*	*	**	**	ns	*
p*o	**	**	ns	ns	**	**	ns	ns
s*v*p	**	**	ns	ns	**	*	ns	ns
s*p*o	**	**	**	ns	**	*	*	ns
v*p*o	**	**	*	ns	**	*	ns	ns
s*v*o	*	**	**	ns	*	**	**	ns
s*v*p*o	**	**	**	ns	**	*	*	ns

***, **, *** and NS: significant at p ≤ 0.05, 0.01, 0.001or not significant, respectively. Means separated at P≤ 0.05, LSD test.**

Interaction effects:

The highest amount of total sugar compounds during all storage periods was noticed for Fuseau tubers treating with spearmint oil and kept in HDPE packages after 10 months of storage in the two seasons while, the lowest one was in Local cultivar tubers without treated oil and kept in PP packages after 4 months of storage in the two seasons (Fig 5). In this regard, Fuseau tubers with black cumin oil kept in PP packages after 10 months of storage in the two seasons recorded the highest reducing sugars but Fuseau tubers with black cumin oil kept in HDPE packages after 4 months of storage in the two seasons. Local cultivar tubers with black cumin oil kept in HDPE packages after 4 months of storage in the two seasons showed the highest inulin %. Local cultivar tubers with black cumin oil kept in PP packages after 2 months of storage caused the highly TSS in the two seasons. Maintaining an optimum atmosphere during storage is effective in delaying quality deterioration, in addition to more inhibition of a wide range of plant pathogens (Yahia, 2007). To inhibit these biochemical activities, the essential oil is widely used (Norkulova and Safarov, 2015). These results are in the same trend with El-Awady and Ghoneem, (2011) and Ghoneem *et al.,* (2016). The increase in TSS and sugar content may be due to the hydrolysis of insoluble polysaccharides into simple sugars. Such changes are expected to be slower and more gradual when the metabolism of the commodity is slowed down by the application of various coating treatments, pre-cooling and under low-temperature storage (Anjum Malik *et al.*, 2016)

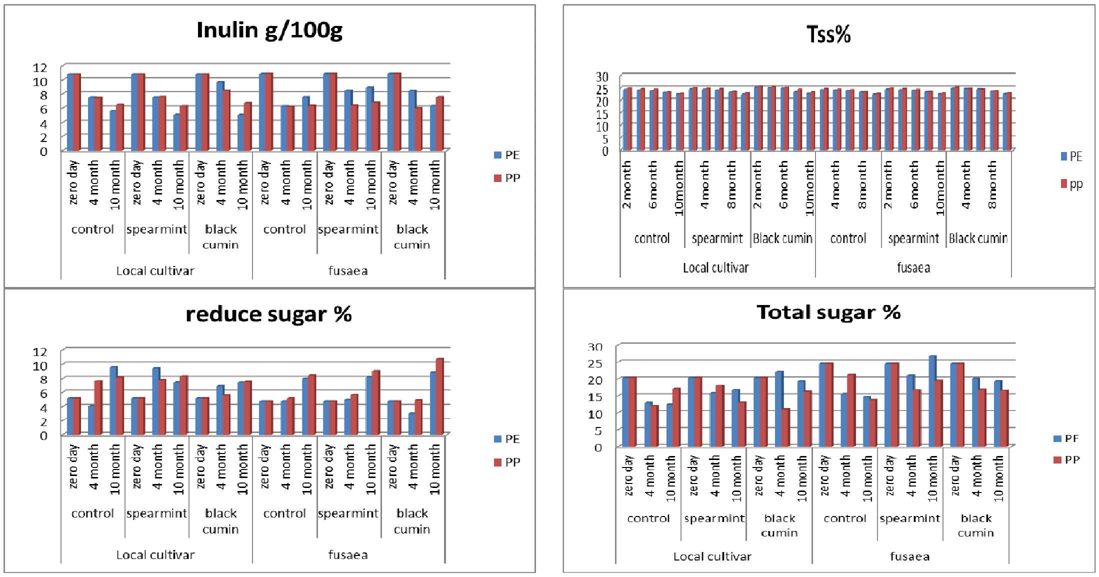


Fig 5. The interaction effect between storage periods, packaging materials and oil treatments on inulin g/100g, TSS, total and reduce sugar % of the two cultivars for Jerusalem artichoke fresh tubers (means of the two seasons).

CONCLUSION

The important consideration in this experiment is the use of the best package, oil treatment and storage period for maintaining the highest quality of the two varieties of Jerusalem artichoke tubers under storage in 4 ˚C. So, it is necessary to have knowledge about the most suitable packaging material in cold storage and the best oil types for storage Jerusalem artichoke variety "Local cultivar and Fuseau". Thus, the view existed from using Local cultivar tubers soaking in diluted black cumin oil 2ml/l, packaging in perforated polypropylene and cold storage at 4˚C was the best in minimizing tuber loss in weight, unmarketable percentage (decay%) increasing dry matter, general appearance and reducing sugars at all the storage periods or, using Fuseau tubers in diluted spearmint oil 2ml/l, wrapping in perforated HDPE package and cold storage at 4˚C resulted in reducing sprouting % and microbial load and increasing in inulin, TSS and total sugars content. Therefore, storage in the perforated PP, which allows maintaining high firmness - one of the most important traits of j. artichoke quality. In addition, essential oils provide an environmentally acceptable alternative to the sprout-inhibition chemicals now in uses.

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تأثير مواد التعبئة والتغليف والزيوت العطرية على الجودة والقدرة التخزينية لدرنات الطرطوفة الطازجة

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إزداد الإقبال فى السنوات القليلة الماضية على الطرطوفة كاحد الخضروات الجديدة التي ظهرت في الأسواق. ولتحسين القدرة التخزينية لهذه الدرنات تم دراسة نوعين من العبوات (البولى بروبلين والبولي إثيلين عالي الكثافة المثقب) ونوعين من الزيوت (زيت حبة البركة وزيت النعناع) بالمقارنة بالكنترول غيرالمعامل بالزيوت على صنفين من الطرطوفة (الصنف المحلى والفيوزا) والتخزين على درجة 4°م ورطوبة نسبيية 90- 95٪ لمدة 10 اشهر وتم تقدير هذه القياسات دوريا كل شهرين(الفقد فى الوزن، نسبة التلف، المادة الجافة،المظهر,الحمل الميكروبى العدد الكلى & الفطر والخمائر, المواد الصلبة الذائبة الكلية، الإينولين، محتوى السكريات الكلية والمختزلة ونسبة التنبيت).أظهرت النتائج تفوق الصنف المحلى فى كل الصفات الفيزيائية والكيميائية ماعدا نسبة الانيولين والمحتوى الكلى للسكريات فقد تفوق عنه صنف الفيوزا.علاوة على ذلك وجد ان التخزين فى عبوات البولى بروبلين المثقبة قلل الفقد فى الوزن و نسبة التلف وزيادة نسبة المادة الجافة ومحتوى السكريات المختزلة وجودة المظهر العام.وفى المقابل فان عبوات البولى اثيلين عالية الكثافة اظهرت اقل حمل ميكروبى ونسبة تنبيت واعلى نسبة انيولين و سكريات كلية ومواد صلبة ذائبة كلية. بالاضافة الى ذالك فان معاملة الدرنات بزيت النعناع وزيت حبة البركة المعبأة فى عبوات البولى بروبلين والبولى اثيلين عالى الكثافة المثقب قد قللت من نسبة الفقد فى الوزن بحوالى 63% عن الكنترول و نسبة التلف وصلت صفر% خلال الشهور الاربعة الاولى وتقليل الحمل الميكروبى وقللت نسبة التنبيت بحوالى 72.09% والمحافظة على جودة المظهر العام بالمقارنة بالكنترول .عموما توصى هذه الدراسة بتخزين درنات الصنف المحلى بعد معاملتها بزيت حبة البركة والتغليف بعبوات البولى بروبلين على درجة 4°م ورطوبة نسبيية90 - 95٪ حيث أظهرت انخفاض معنوي في نسبة الفقد فى الوزن(16%) ونسبة التلف (18%) مع المحافظة على المظهر العام ومعظم الصفات الفيزيائية والكيميائية بحالة جيدة لمدة 10اشهر.