**Shelf life of cauliflower in different packages stored under two temperature regimes**

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| ***Abstract***  **In Norway today, cauliflower (**[***Brassica oleracea***](https://en.wikipedia.org/wiki/Brassica_oleracea)**L. var. *botrytis*) is not packaged before distribution and sales in grocery stores. Unpackaged cauliflower heads are prone to weight loss giving rubbery texture, loose florets and yellow and withered leaves. The aim of this work was to evaluate the performance of three different packaging materials for cauliflower with unpackaged product as control. Quality and shelf life was evaluated during 16 days of storage in darkness at 4 °C (‘Cold storage’) or 4 days in darkness at 4 °C + 3 days in light at 19 °C + 9 days in darkness at 4 °C (‘Realistic storage’). The different packages were 1: polypropylene (PP) flowpack film with 40 needle perforations (‘Low- perf’), 2: PP flowpack film with a row of 560 needle perforations per 10 x 10 cm in the middle (‘High-perf’) and 3: polyethylene cling film (‘Cling’). The weight loss was 10% for unpackaged cauliflower and below 1% for the packaged products stored at cold conditions for 16 days. At ‘Realistic storage’ conditions, weight loss was 19% for unpackaged cauliflowers, 2.6% for the ‘High-perf’ film and below 1% for the ‘Low-perf’ film and the ‘Cling’ film. ‘Realistic storage’, including 3 days at room temperature, had the highest effect on development of black spots (mould) on the cauliflower heads, whereas limited effect was found for the different packaging materials on black spot development. Packaged cauliflower had firmer heads and better leaf quality than unpackaged samples. Cauliflower may benefit from packaging in order to inhibit weight loss and quality degradation, but packaged products stored for a short period at room temperature have increased risk of black spot development. Cold display in the grocery shops will give the best quality and longest shelf life for both packaged and unpackaged cauliflower.** |
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**Keywords:** *Brassica oleraceae* L. var. *botrytis*, abused temperature, packaging materials, perforations, weight loss, quality degradation

**INTRODUCTION**

Cauliflower is a popular vegetable in the *Brassicaceae* family and an important meal component in a healthy diet. During the last three decades, the worldwide production of cauliflowers and broccoli has more than tripled (FAO, 2016). Cauliflower is a cool season crop and well suited for summer and fall production in Southern Norway. However, postharvest handling of the produce can be challenging. Cauliflower have a high respiration rate giving a relatively short shelf life, and is prone to physical injury and susceptible to microbial growth (DeEll et al., 2003; Suslow and Cantwell, 1998). Fresh cauliflower should have a firm and compact head of white to cream white curds surrounded by a crown of well-trimmed, turgid green leaves. In addition, there should be no yellowing due to sunlight exposure or “riciness” due to loose or protruding floral parts that is a sign of over-maturity (DeEll et al., 2003; Suslow and Cantwell, 1998). Given optimum storage conditions, the expected shelf life of cauliflower is three weeks (Dhall et al., 2010; Suslow and Cantwell, 1998).

In Norway today, cauliflower is not packaged before distribution and sale in grocery stores. Unpackaged cauliflower heads are prone to weight loss giving rubbery texture, loose florets and yellow and withered leaves. On exports from Spain to destinations in European countries less than 5% weight loss is permissible in order to avoid wilting, shrivelling and other senescence symptoms (Artés and Martínez, 1999). Packaging enables shelf life extension by creating high-humidity environment reducing weight loss and shrinkage (Porat, et al., 2018). However, it is important to design appropriate packaging systems that allows proper cooling and gas exchange matching the storage temperatures and the respiration rate of the produce throughout the distribution chain.

Cauliflower do not benefit from storage in controlled or modified atmospheres with high CO2-levels. Atmospheres containing O2 levels below 2% and CO2 levels above 5% can induce physiological disorders and symptoms of injury such as off-odours, softening and discoloration (Romo‐Parada et al., 1989; Suslow and Cantwell, 1998). In order to avoid detrimental high levels of CO2 in the packages, the packages must have very high gas transmission rates or they have to be perforated. The perforation must be adapted to the highest storage temperature in the distribution chain (Larsen and Wold, 2016).

In Norway, the cauliflower are usually cooled down to 1-2 °C immediately after harvest and kept at 2-4 °C during transport to wholesaler and distribution to grocery stores. During retail, some grocery stores display cauliflower in chill cabinets, whereas others display them at ambient temperature. For the latter, cauliflower may be kept at room temperature for one to three days. Consumers usually store cauliflower in the fridge.

The aim of this work was to evaluate the performance of three different packaging materials for cauliflower, with unpackaged product as control. The trial was adapted to the temperature and storage facilities available at the packinghouses today and realistic time and temperature scenarios in the distribution chain including storage by consumers.

**MATERIALS AND METHODS**

**Packaging and storage**

Commercially mature cauliflowers ([*Brassica oleracea*](https://en.wikipedia.org/wiki/Brassica_oleracea)L. var. *botrytis* cv. Delfino), weight 604 ± 119 g, were harvested in Stokke in Vestfold (south of Norway) in September 2016. The cauliflowers were stored at 2 °C for 3 days before start of the experiment. Leaves were trimmed by hand before packaging at Nofima. The cauliflowers were left unpackaged (control) or manually packaged in the lab using three different packaging materials: 1) 35 µm polypropylene (PP) flowpack film (laminate of 15 µm oriented PP and 20 µm cast PP) (SP Group, Cordoba, Spain) with 40 perforations (200 x 2-3 µm) manually made by a needle; hereafter denoted ‘Low-perf’, 2) 40 µm biaxially oriented PP flowpack film with a row of 560 needle perforations (90 x 13 µm) per 10 x 10 cm in the middle (Tommen Gram Folie, Levanger, Norway); hereafter denoted ‘High-perf’, and 3) 11 µm polyethylene (PE) cling film (Crocco SpA, Vicenza, Italy); hereafter denoted ‘Cling’ film. Package 1 and 2 were heat sealed, whereas film 3 was manually wrapped.

During the experiment, the cauliflowers were stored in climate rooms at Nofima for 1) 16 days in darkness at 4 °C (‘Cold storage’) or 2) 4 days in darkness at 4 °C + 3 days in light at 19 °C + 9 days in darkness at 4 °C (‘Realistic storage’). The two treatments simulate storage conditions from harvest to consumption including display in chill cabinets or at room temperature, respectively. The light source was Osram HO 49W/840 Lumilux T5 fluorescent tubes, and the light level was 4.2 W/m2 (1420 Lux) measured with a CL-500A illuminance spectrophotometer (Konica Minolta Sensing Europe B.V., Nordic Filial, Västra Frölunda, Sweden). The light was turned on from 07.00 until 23.00 (16 hours) during 3 days. Temperature during storage was recorded using KoolTrack temperature loggers type 212004 (Palm Beach Gardens, Florida, USA). The temperature was 4.4 ± 0.2 °C in the cold room and 19.1 ± 0.8 °C in the warm room. The relative humidity (RH) in the respective storage rooms was approximately 75% and 30% measured with SL54TH/SL54TH-A temperature and humidity data loggers (Signatrol, Tewkesbury, United Kingdom).

Evaluation of quality was performed at the day of packaging and after 7 (including 3 days at 19 °C for ‘Realistic storage’), 12 and 16 days of storage. Three replicates per treatment were removed from the experiment and evaluated at each sampling time.

***Analyses***

O2 and CO2 concentrations in the headspace of the ‘Low-perf’ packages were measured 3-4 times during storage, using a Checkmate 9900 gas analyser (Dansensor, Ringsted, Denmark). The gas samples were withdrawn through a septum placed on the packages using a needle connected to the gas analyser.

Weight loss was determined by weighing each cauliflower without packaging at the day of packaging, and after 7, 12 or 16 days of storage after removal of packaging. The weight loss was calculated as percentage loss of the initial weight.

Quality loss during storage was evaluated on samples without packaging on day 7, 12 and 16 by our lab team (3 evaluators) using grades 1-5 defined for each quality parameter, and for which grade 3-5 was considered unacceptable for sale. Firmness of cauliflower heads was evaluated by hand pressure and rated according to grade 1 = very firm/tight, 3 = moderately firm/tight, and 5 = very soft/loose. Leaf quality was evaluated visually and by touch, and rated according to grade 1 = fresh green, turgid leaves, 3 = moderately discoloured or limp leaves, and 5 = withered, loose leaves. Decay of cauliflower heads, including discolouration and pathological disorders,was evaluated visually and rated according to grade 1 = no decay, 3 = moderate decay, and 5 = severe decay according to Suslow and Cantwell (1998). On the day of packaging, the cauliflowers were of grade 1 for all quality parameters.

Analysis of variance (ANOVA) was performed for the dataset (α = 0.05) using General linear model in Minitab 17 Statistical Software (Minitab Inc., State College, PA, USA). Means were separated by Tukey’s multiple comparison test for ‘Cold storage’ and ‘Realistic storage’ samples separately (day 7, 12 and 16). Relationship between quality parameters was analysed with fitted line plot regression (α = 0.05).

**RESULTS AND DISCUSSION**

**Headspace gas concentrations**

The gas atmosphere in the headspace of selected ‘Low-perf’ packages was measured 3-4 times during the storage period to monitor the level of CO2 in the packages. The highest CO2 concentration measured in the packages was 3.3% after three days at 19°C. This level was within the acceptable limit of 5% according to findings from Romo‐Parada et al. (1989). The other packages maintained ambient air gas concentrations.

**Weight loss**

Weight loss is influenced by surrounding temperature, humidity and air circulation speed. Weight loss of cauliflower heads was registered after 7, 12 and 16 days of storage (Figure 1).

The weight loss was approximately 10% for unpackaged cauliflower and below 1% for the packaged products stored at cold conditions for 16 days. After 16 days at ‘Realistic storage’, weight loss was 19% for unpackaged cauliflowers, 2.6% for the ‘High-perf’ and below 1% for the ‘Low-perf’ film and the ‘Cling’ film. The total weight loss almost doubled for cauliflower stored at room temperature for 3 days before consecutive storage at cold conditions. Packaging explained 73.5% of the variance for weight loss, whereas temperature explained 7.3% (Table 1). At ‘Realistic’ storage, most of the weight loss occurred within 7 days at storage, which explained the low effect (1.2% of variation) of prolonged storage beyond 7 days.

According to the 5% maximum weight loss limit, as used for exports from Spain to destinations in European countries (Artés and Martínez, 1999), the unpackaged cauliflower was no longer acceptable after 12 days at ‘Cold storage’ and after 7 days at ‘Realistic storage’. All the package materials, including the highly perforated film, kept the weight loss below 4% for 16 days at both storage conditions. Similarly, DeEll et al. (2003) reported weight losses of 11.4-14.7% for unpackaged cauliflower and below 2% for all packaged cauliflower after storage for 23 days at 0-1 °C or 10 °C.

Figure 1. Weight loss for unpackaged or packaged cauliflowers (cv. Delfino) during storage for 16 days in darkness at 4 °C (‘Cold storage’) or 4 days in darkness at 4 °C + 3 days in light at 19 °C + 9 days in darkness at 4 °C (‘Realistic storage’). Treatments with different letters within ‘Cold storage’ and ‘Realistic storage’ are significantly different (*p* < 0.05). Mean of three samples for all treatments.



**Firmness of cauliflower heads**

Firmness of cauliflower heads was evaluated after 7, 12 and 16 days of storage (Figure 2).



Figure 2. Firmness for unpackaged or packaged cauliflowers (cv. Delfino) during storage for 16 days in darkness at 4 °C (‘Cold storage’) or 4 days in darkness at 4 °C + 3 days in light at 19 °C + 9 days in darkness at 4 °C (‘Realistic storage’). Treatments with different letters within ‘Cold storage’ and ‘Realistic storage’ are significantly different (*p* < 0.05). Mean of three samples for all treatments.

All the packaged cauliflower heads had acceptable firmness (≤ 3) at all sampling times, and no significant differences were detected between the packaging materials. Unpackaged cauliflower, however, had unacceptable firmness (≥ 3) after 12 days at ‘Cold storage’ and already after 7 days at ‘Realistic storage’.

Packaging was the main factor explaining 72% of the variation in firmness. The retention of firmness in packaged products was probably due to lower moisture loss. Firmness was positively correlated with the weight loss data (*R2* = 0.77, *p* < 0.001, Figure 3). Weight loss above 5% resulted in unacceptable firmness (≥ 3), which is in accordance with the limit for permissible weight loss reported by Artés and Martínez (1999).



Figure 3. Relationship between firmness and weight loss in unpackaged and packaged cauliflower heads (cv. Delfino) during storage for 16 days in darkness at 4 °C (‘Cold storage’) or 4 days in darkness at 4 °C + 3 days in light at 19 °C + 9 days in darkness at 4 °C (‘Realistic storage’).

**Leaf quality**

Leaf quality was evaluated after 7, 12 and 16 days of storage (Figure 4). Similar to the results for cauliflower head firmness, leaf quality was positively correlated to weight loss during storage (*R2* = 0.54, *p* < 0.001). Unpackaged cauliflower had most wilting and loose leaves at both storage regimes. All the packaged cauliflowers retained acceptable leaf quality during ‘Cold storage’, except for the samples packaged 16 days in the ‘High-perf’ film. Only the samples packaged in ‘Low-perf’ film retained acceptable leaf quality (< 3) during ‘Realistic storage’.

Packaging explained 50% and temperature 20% of the sample variation for leaf quality. The better leaf quality at day 12 than at day 7 during ‘Realistic storage’ can be explained by moisture absorption by the leaves when the cauliflowers were moved from 19 °C and 30% RH to 4 °C and 75% RH. The leaf quality decreased again on day 16, mostly due to discoloration of cut surfaces for the packaged cauliflower and to wilting for the unpackaged controls.

Figure 4. Leaf quality for unpackaged or packaged cauliflowers (cv. Delfino) during storage for 16 days in darkness at 4 °C (‘Cold storage’) or 4 days in darkness at 4 °C + 3 days in light at 19 °C + 9 days in darkness at 4 °C (‘Realistic storage’). Treatments with different letters within ‘Cold storage’ and ‘Realistic storage’ are significantly different (*p* < 0.05). Mean of three samples for all treatments.



**Decay of cauliflower head**

The decay of cauliflower heads during storage was evaluated using a scale from 1 (no decay) to 5 (severe decay) (Figure 5).



Figure 5. Decay in unpackaged or packaged cauliflowers (cv. Delfino) during storage for 16 days in darkness at 4 °C (‘Cold storage’) or 4 days in darkness at 4 °C + 3 days in light at 19 °C + 9 days in darkness at 4 °C (‘Realistic storage’). Treatments with different letters within ‘Cold storage’ and ‘Realistic storage’ are significantly different (*p* < 0.05). Mean of three samples for all treatments.

No significant differences were detected for over-all decay development between the three types of packaging during ‘Cold storage’ or ‘Realistic storage’. A tendency to more decay was observed for unpackaged samples after 16 days of storage. The most severe decay

was observed at ‘Realistic storage’, for which the cauliflowers had high levels of decay (> 2) already after 2 days at 19 °C. Effect of temperature explained 31% of the variation between the samples, whereas duration of storage explained 16% (Table 1).

The causes of decay differed between packages and storage conditions (data not shown). Whereas pale brown spots were observed in various degree for all treatments, black spots (moulds) were only observed in packaged cauliflowers at ‘Realistic storage’ and at the most in ‘Low-perf’ film. These were also the treatments producing the highest amount of free water inside the packaging. A couple of random incidents of bacterial soft rot were also observed in ‘Cold storage’ cauliflowers packaged in ‘Low-perf’ film and ‘Cling’ film. Dhall et al. (2010) observed that surface blackening and rotting due to disease increased for cauliflower during storage at 0±1 °C at 90-95% RH for 28 days irrespective of type of packaging. González-Fandos and Simón (2016) reported a slight incidence of moulds to be the main problem when cauliflower florets were stored in modified atmosphere packaging for 13 days at 5 °C. Washing the cauliflower with an antimicrobial can probably reduce the growth of moulds, but this may not be welcomed by the industry and consumers in Norway.

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| Table 1. Analysis of variance for experimental factors in storage trial with packaged and unpackaged cauliflowers (cv. Delfino) stored for 16 days at 4 °C (‘Cold storage’) or 4 days in darkness at 4 °C + 3 days in light at 19 °C + 9 days in darkness at 4 °C (‘Realistic storage’).  Quality evaluations on day 7, 12 and 16 are included in the analysis. | | | | | | | | |
|  | **Weight loss** | | **Decay** | | **Firmness** | | **Leaf quality** | |
| Factor | % of variance | P-value | % of variance | P-value | % of variance | P-value | % of variance | P-value |
| Day  Packaging  Temp  Day\*Pack  Day\*Temp  Pack\*Temp  Error | 1.2  73.5  7.3  2.0  0.2  14.1  1.7 | **0.00**  **0.00**  **0.00**  **0.00**  **0.03**  **0.00** | 15.6  1.1  30.8  10.3  0.9  3.5  37.9 | **0.00**  0.66  **0.00**  **0.04**  0.53  0.19 | 10.8  72.2  1.8  3.0  0.2  2.0  10.0 | **0.00**  **0.00**  **0.00**  **0.02**  0.59  **0.02** | 11.1  49.8  20.0  2.3  8.4  0.8  7.5 | **0.00**  **0.00**  **0.00**  **0.02**  **0.00**  0.15 |
| Total | 100 |  | 100 |  | 100 |  | 100 |  |

**CONCLUSIONS**

Unpackaged cauliflowers had major weight loss, less firm heads and inferior leaf quality compared to packaged cauliflowers after 16 days of storage, especially when the storage included a period of 3 days at room temperature simulating realistic conditions. Packaged cauliflower had weight loss below 5%, firm heads and acceptable leaf quality at ‘Cold storage’. Room temperature storage for 3 days had a negative effect on cauliflower decay. The type of packaging had insignificant effect on the development of decay.

Cauliflower may benefit from packaging in order to inhibit weight loss and quality degradation, but packaged products stored for a short period at room temperature have increased risk of black spot development. Cold display in the grocery shops will give the best quality and longest shelf life for both packaged and unpackaged cauliflower. Benefits of packaging of cauliflower before cold storage must be evaluated against the major trend in Norway of reduced use of plastic materials for fruit and vegetables due to environmental concerns.

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