RECENT ADVANCES IN LOW O_2 AND LOW ETHYLENE STORAGE OF APPLES IN POLAND

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The apple production in Poland in the period 1981-1984 ranged from 1.7 to 2.1 million tons annually. Part of the crop are summer apples. The main apple cultivars are McIntosh, Spartan, Idared, Cortland, Jonathan, Bancroft, Melrose, and some other cultivars of minor importance. Polish growers are encountering great difficulties in marketing apples because a tremendous amount of apples is supplied on the market in a rather short time.

The total apple storage capacity in Poland amounts only less than 500 thousand tons. However, only about 100 thousand tons of apples are stored in refrigerated stores, and about 400 thousand tons in common stores, cooled by cold air during the night. Apples stored in common stores ripen too fast, loose their quality and contribute to the excess supply of the market.

Therefore there exists a great interest in extending the storage period and in raising the quality of apples supplied on the market. Controlled atmosphere storage in addition to expanding the amount of refrigerated storage in normal air should be developed, to improve the situation in the fruit trade. CA will enable extension of the storage period and supplying the domestic as well as foreign market with fresh, firm fruits in the spring.

The first CA rooms were constructed in 1968. Now the total capacity of CA stores amounts about 25 thousand tons of apples. Almost entirely domestic equipment is used in CA stores - activated carbon CO_2 scrubbers, O_2 converters, ethylene scrubbers and gas tight materials have been developed.

Experimentation with CA storage of apples began in Poland in 1962. Up to now approximately 20 apple cultivars have been tested. During the first years apples were stored in standard CA atmosphere of 5% CO_2 + 3% O_2, and in 5% CO_2 + 16% O_2 and 0% CO_2 + 3% O_2. The standard CA atmosphere 5% CO_2 + 3% O_2 proved to give best results - the softening of apples was the slowest.

Low Oxygen Storage

After North et al. (24) reported that Cox's Orange Pippen apples may be stored in 1% O_2 at least for 28 weeks, and after Lougheed et al. (23) reported that McIntosh, Empire and Spartan apples may be stored in low O_2,

we started research with low O_2 storage of McIntosh apples in the storage season 1978/79. The results obtained with McIntosh after 150 days storage in 2% CO_2 + 1-1.5% O_2 were surprisingly good. Apples maintained very high flesh firmness (7.2 kgf) after storage at 3°C versus 8.5 kgf at harvest and 5.5 kgf at 5% CO_2 + 3% O_2. This high firmness persisted even after additional storage for 7 days at 18°C. The overall quality of the apples was excellent. Apples stored in 0% CO_2 + 1-1.5% O_2 were as good or almost as good as apples stored in 2% CO_2 + 1-1.5% O_2 (Table 1). These two gas compositions retarded fruit softening the most. It was thus obvious that the threshold of O_2 for apple storage is lower than 2% and that there exists possibility in storing apples in atmospheres with O_2 close to 1%.

Further reports from abroad have shown that McIntosh (4,17,18,19), Golden Delicious (18), Spartan (23), and Empire (23) apples stored in low oxygen atmospheres maintain higher flesh firmness and better quality than when stored in the conventional controlled atmosphere.

Six year's storage results with McIntosh apples in Poland (12,13) have also shown that low O_2 atmospheres retard ripening and flesh softening much more than the standard CA atmosphere 5% CO_2 + 3% O_2.

Lowering O_2 from 3% to 1.5% and maintaining it in a range within ±0.2-0.3 results in higher fruit firmness and acidity (Table 1) and juice content after cold storage and after a 7-day shelf life period, than conventionally stored apples. The retention of firmness of apples stored in 2% CO_2 + 2% O_2 is very much like that of apples stored in 5% CO_2 + 3% O_2. Two percent of O_2 is still too much to retard significantly softening and firmness loss. However, the most significant effect on retarding softening was in 1% CO_2 + 1% O_2. Apples stored in 1% CO_2 + 1% O_2 and in 2% CO_2 maintained the highest flesh firmness and titratable acidity and looked very much like apples freshly harvested. When these apples were stored at 18° to 20°Cfor several weeks they did not show symptoms of normal ripening.

McIntosh apples stored in 2% CO_2 + 1.5% O_2, 0% CO_2 + 1.5% O_2, 1% CO_2 + 1% O_22, and 0% CO_2 + 1% O_2 have not shown core flush or any other physiological disorder. However, core flush was observed in fruits from 2% CO_2 + 1% O_2 atmosphere.

McIntosh apples stored in 0% CO_2 + 1% O_2 and 0% CO_2 + 1.5% O_2 were usually also firmer than those stored in 5% CO_22 + 3% O_2. The skin colour of these apples was usually bright green, more appealing to consumers, than of those stored in low O_2 with CO_2.

Fruits of other cultivars, like Spartan and Melrose, and also Bancroft and Cortland (results not shown here) retained the highest flesh (14,15,16) firmness, similarly to McIntosh, in 2% CO_2 + 1.5% O_2. The only exception was Idared apples, which have shown core flush in every gas composition applied. Up to now we have had bad experience with CA storage of Idared apples, and the best storage results were obtained by the farmers when stored in common stores. We have never observed low oxygen

preclimacteric stage is a necessary condition for apples to be benefited by ethylene removal in CA for the studies conducted in 1980-84, the fruit of the apple cultivar McIntosh, Spartan and Golden Delicious were harvested in preclimacteric stage. To verify whether or not the apples were preclimacteric the ethylene content in the seed cavities of fruits was measured. For the storage season 1980-81 McIntosh apples were picked at the time when the commercial apples were harvested. For the storage season 1984-85 McIntosh apples were harvested twice for the experiment. The first picking was at the time of commercial harvest on September 19 when the apples contained less than 0.1 ppm ethylene. The second picking was on September 27, and the apples still had a low internal ethylene level. It may be mentioned here that one year earlier, in 1983, McIntosh apples from trees on another rootstock contained very high internal ethylene by September 2. This means that under climatic conditions in Poland the maturity of apples differs from year to year very much. This is influenced mostly by climate but also by rootstocks of which several types are used in Poland.

In the preliminary studies in the season 1980-81 McIntosh apples stored in low ethylene CA with 2% CO_2 + 1.5% O_2 were significantly firmer than apples stored in high ethylene. In 5% CO_2 + 3% O_2 there were no differences in firmness. In the storage season 1984-85 McIntosh apples of both harvests were preclimacteric. Apples of both pickings stored in 5% CO_2 + 3% O_2 with ethylene at less than 1 ppm were significantly firmer after storage at 3°C and after additional storage at 18°C than apples stored under high ethylene conditions. Apples from second harvest stored in 2% CO_2 + 2% O_2 LE, 0% CO_2 + 1% O_2 LE and in 5% CO_2 + 3% O_2 LE were also significantly firmer than apples stored with ethylene at a high level. However, after the storage at 18°C the differences in flesh firmness leveled off. It should be noticed that apples stored under low ethylene conditions exhibited slight core flush.

Spartan apples used for experiment in the storage season 1984-85 were harvested on September 26 and October 4. At the first harvest 7 apples out of 10 had an ethylene content higher than 0.1 ppm and 3 apples contained 5-10 ppm. At the second harvest 9 out of 10 apples had more than 0.1 ppm and 5 apples contained more than 10 ppm. The apples were stored in similar atmospheres as McIntosh apples. Only apples which were stored in 5% CO_2 + 3% O_2 responded to ethylene removal and the firmness of these apples stored under low ethylene (LE) conditions was significantly higher than that of apples stored under high ethylene conditions. Here again, as with McIntosh apples, the flesh firmness after additional storage for 7 days at 18°C leveled off. There were no significant differences in acid content between apples stored in CA under high (HE) and low (LE) ethylene level. Spartan apples from first picking stored in 5% CO_2 + 3% O_2 LE exhibited core flush after additional storage for 7 days at 18°C (Table 2,3).

Golden Delicious apples harvested at the preclimacteric stage were stored in two seasons. For the 1982-83 season apples were harvested twice, on Sept. 28 (immature) and October 7 (mature). Apples from both

injuries in the experiments.

In conclusion it can be said that low oxygen levels of 1 and 1.5% with CO_2 at 1 and 2% during the CA storage of McIntosh apples strongly retard flesh softening in comparison with 5% CO_2 and 3% O_2. Retardation of flesh softening in 2% CO_2 + 2% O_2 is similar to that in 5% CO_2 + 3% O_2. The gas composition 2% CO_2 + 1% O_2 may cause core flush and it is proposed to lower CO_2 content if the oxygen is maintained on the level of 1%. While storing McIntosh apples in 1% CO_2 + 1% O_2 strongly retards softening, it leads to abnormal ripening. Storing of McIntosh apples in 0% CO_2 atmospheres with O_2 at 1 to 1.5% retards softening but not as much as atmospheres with CO_2, but this is better than the standard CA of 5% CO_2 + 3% O_2. Gas composition of 0% CO_2 + 3% O_2 is of no value for McIntosh apple storage. For the long term CA storage of McIntosh apples in Poland, the best atmospheres to employ are 2% CO_2 + 1.5% O_2 or 1% CO_2 + 1-1.5% O_2. Spartan and Melrose apples have shown greatest firmness retention in 2% CO_2 + 1.5% O_2.

Low Ethylene Storage

Since the work of Kidd and West in England it has been known that limiting oxygen supply to fruit retarded ripening and that ethylene is responsible for ripening. Further studies have also shown that ethylene produced by the fruits itself promotes ripening and senescence of apples stored in CA and hypobaric conditions (8,1). It was reported also that fruits should be in the preclimacteric stage to be benefited by ethylene removal (20).

In 1969 Forsyth et al. (7) reported that McIntosh apples stored for 189 days at 3.3°C in CA with ethylene at a low level were 2 lbs higher in flesh firmness than apples from atmospheres with ethylene. Then other researchers confirmed the information that lowering ethylene in CA retards flesh firmness loss of apples (2,9,10,13,20,21,22,25). Among the methods applied for ethylene removal, very effective was the LPS storage of apples (3). Dilley has shown (5,6) that McIntosh apples and apples of other cultivars stored under 0.1 atmosphere storage pressure maintained very high flesh firmness. Fruits stored under hypobaric conditions ripened and softened slowly because no ripening took place under hyponormal ethylene level. It is well known for many years that only few ppm of ethylene in the atmosphere is sufficient to cause fruit ripening, and it is also well known that ethylene accumulates in CA atmospheres to several hundred or even thousand ppm. It is necessary and now possible to remove most of the ethylene from the environment of the fruit. The ethylene inside rather than outside the fruit is involved in ripening, it is necessary to restrict ethylene production by the fruit and to inhibit the action of ethylene. The ethylene content in the fruit should be kept to less than 1 ppm.

In our experiments the ethylene content in the atmosphere surrounding the fruit was maintained by a flow through ethylene scrubber with a heated catalyst. The ethylene scrubber worked in a closed circuit. Since the

pickings responded to ethylene removal when stored 230 days in 5% CO_2 + 3% O_2 at 3°C, and from the second picking when stored in 2% CO_2 + 2% O_2. However, after additional storage for 7 days at 18°C there were no differences in flesh firmness. In the storage season 1983-84 preclimacteric Golden Delicious apples also responded to ethylene removal when stored in standard CA at 3°C. After additional storage for 7 days at 18°C the flesh firmness differences still existed. The apples previously stored in standard CA maintained significantly higher firmness.

In conclusion, McIntosh, Spartan, Golden Delicious and Jonathan apples ripen more slowly during CA storage at 5% CO_2 + 3% O_2 when ethylene is removed than when ethylene is allowed to accumulate in the storage atmosphere. Ethylene removal during CA storage at 1% CO_2 + 1% O_2 delayed ripening of Jonathan apples but the other cultivars showed no differences whether or not ethylene was removed. The effects of ethylene removal during CA storage at 2% CO_2 + 2% O_2 were not always evident. Research is being continued.

Table 1.

Response of apple cultivars to low oxygen CA storage

Storage atmosphere % CO_2 + % O_2	Flesh firmness kgf after storage at 3°C	at 18°C	Titratable acids mg malic/100g f.w. after storage at 3°C	at 18°C	Core flush % of fruits at 3°C	at 18°C	Flesh browning % of fruits at 3°C	at 18°C	Superficial scald % of fruits at 3°C	at 18°C	
1	2		3		4		5		6		7
Mc Intosh - 1978/79; 150 days of storage; harvested Sept. 20; firmness 8,5 kgf; titr.ac. 733 mg m.a./100g fw.											
Normal	4,7	3,4			100	100	0	0	17	71	
5 + 3	5,7	5,1			0	0	0	0	0	0	
5 + 16	4,9	4,6			17	83	0	0	0	17	
0 + 2,5-3	5,3	4,7			8	100	41	50	0	29	
0 + 1-1,5	7,3	6,0			0	0	0	6	0	0	
2 + 2,5-3	6,4	5,5			0	0	0	2	0	0	
2 + 1-1,5	7,2	6,8			0	0	0	0	0	0	
McIntosh - 1979/80; 150 days of storage; harvested Sept. 15; titr.ac. 780 mg m.a./100gfw.;firmness 7,2 kgf											
Normal	3,8	3,5	335	278	17	65	0	0	16	50	
5 + 3	4,5	4,1	513	402	0	0	0	0	0	0	
2 + 1,5	5,9	5,1	525	444	0	0	0	0	0	0	
0 + 3	4,5	4,1	386	369	0,7	0	49	44	0,4	4	
0 + 1,5	5,3	5,0	451	412	0	0	7	5	0	0	
McIntosh - 1980/81; 190 days of storage; harvested Sept. 18; firmness 7,5 kgf; titr.ac. 804 mg m.a./100g fw.											
Normal	3,7	-	297	-	100	-	0	0	100	-	
5 + 3	5,5	4,7	503	-	0	12	0	0	0	0	
0 + 3	4,4	4,1	431	-	0	0	0	0	0,4		
2 + 1,5	6,7	5,8	511	-	0	0	0	0	0	0	
0 + 1,5	6,2	5,3	496	-	0	0	0	0	0	0	
McIntosh - 1981/82; 270[x] days of storage, harvested Sept. 16; firmness 7,3 kgf; titr.ac. 771 mg m.a./100g fw.											
Normal	3,3	-	-	-	85	-	0	-	-	-	
5 + 3	4,3	-	410	-	0	15	0	0	0	0	0 11
2 + 1,5	5,5	5,2	415	-	0	0	0	0	0	0	corky spots incidently
1 + 1	6,2	5,4	455	-	0	0	0	0	0	0	
McIntosh - 1982/83; 215[x] days of storage; harvested Sept. 16; firmness 7,9 kgf; titr.ac. 760 mg m.a./100g fw.											
Normal	3,7	-	-	-	46	-	-	-	2	10	
5 + 3	4,2	4,0	483	-	0	0	0	0	0	0	
2 + 2	4,7	4,1	476	-	0	0	0	0	0	0	
1 + 1	6,2	5,2	503	-	0	0	0	0	0	0	

[x] Apples from normal atmosphere removed ealier

Cont.table 1.

1	2		3		4		5		6		7
McIntosh - 1984/85; 194 days of storage; harvested Sept. 27; firmness 5,5 kgf; titr.ac. 686 mg m.a./100g fw.											
Normal	3,7	-	240	-	90	-	-	0	-	-	
5 + 3	5,3	4,9	407	353	0	10	0	0	0	0	
2 + 2	5,2	4,8	393	373	0	0	0	0	0	0	
2 + 1	5,7	5,5	430	413	0	15	0	0	0	0	
0 + 1	5,4	5,4	437	403	0	0	0	0	0	0	
Spartan - 1979/80; 180 days of storage; harvested Sept. 25, firmness 7,7 kgf; titr.ac.502 mg m.a./100g fw.											
Normal	4,8	4,3	218	164	4	44	0	0	0	0	
5 + 3	5,4	5,1	347	271	0	1	0	0	0	0	
2 + 1,5	6,6	5,9	349	265	0	0	0	0	0	0	
0 + 1,5	5,6	5,2	315	263	0	0	0	0	0	0	
Spartan-1980/81; 180 days of storage; harvested Oct. 10; firmness 7,6 kgf; titr.ac. 556 mg m.a./100g fw.											
Normal	5,3	4,9	230	-	82	100	0	0	3	3	
5 + 3	6,0	5,4	360	-	35	48	0	0	0	0	
2 + 1,5	7,0	6,5	350	-	12	15	0	0	0	0	
0 + 1,5	6,1	5,8	350	-	0	6	0	0	0	0	
Melrose - 1979/80; 200 days of storage; harvested Oct. 16; firmness 7,4 kgf; titr.ac. 494 mg m.a./100g fw.											
Normal	4,6	4,4	375	-	0	0	0	0	28	51	
5 + 3	6,1	5,4	448	-	0	0	0	0	11	14	
2 + 1,5	6,0	5,5	429	-	0	0	0	0	8	11	
0 + 1,5	5,5	5,1	419	-	0	0	0	0	2	7	
Melrose - 1980/81; 200 days of storage; harvested Oct. 20; firmness 7,9 kgf; titr.ac. 657 mg m.a./100g fw.											
Normal	5,8	5,5	370	-	0	0	0	0	43	57	
5 + 3	7,2	6,1	430	-	0	0	0	0	0	0	
2 + 1,5	7,8	6,9	470	-	0	0	0	0	0	0	
0 + 1,5	7,3	6,6	480	-	0	0	0	0	0	0	
Idared - 1979/80; 200 days of storage; harvested Oct. 12; firmness 7,6 kgf; titr.ac. 810 mg m.a./100g fw.											
Normal	5,4	5,1	362	-	0	10	0	0	0	0	
5 + 3	6,8	6,1	407	-	0	36	0	0	0	0	
2 + 1,5	6,7	5,8	465	-	0	39	0	0	0	0	
0 + 1,5	5,6	5,1	426	-	0	22	0	0	0	0	
Idared-1980/81; 186 days of storage; harvested Oct. 17; firmness 9,4 kgf, titr.ac. 583 mg m.a./100g fw.											
Normal	7,3	6,9	280	-	35	76	0	0	0	0	
5 + 3	8,8	7,7	330	-	0	99	0	0	0	0	
2 + 1,5	8,6	7,5	300	-	0	83	0	0	0	0	
0 + 1,5	7,8	7,1	330	-	0	80	0	0	0	0	

Table 2.

The effect of low ethylene controlled atmosphere storage on McIntosh apples

a/ McIntosh - storage season and harvest day - 1980/81; Sep. 18; storage duration at 3°C - 190 days; flesh firmness /kgf/ at harvest - 7,5; titratable acids /mg malic/100g fw./ - 604

Storage atmosphere % CO_2 + % O_2	Flesh firmness after storage: 3°C HE	3°C LE	6-7 days in: 18°C HE	18°C LE	Titratable acids after storage: 3°C HE	3°C LE	6-7 days in: 18°C HE	18°C LE	Physiological disorders % of fruits: 3°C HE	3°C LE	6-7 days in: 18°C HE	18°C LE
5 + 3	5,5	5,7	4,3	4;7	502	468	-	-	0	0	0	0
0 + 3	4,4	4,3	4,0	4,0	389	431	-	-	100fb	100fb	-	-
2 + 1,5	6,7	7,2χ	6,0	5,9	513	511	-	-	0	0	0	0
0 + 1,5	6,2	6,1	-	-	496	451	-	-	0	0	0	0
N	3,7		-	-	297		-	-	100cf		100cf 100ss	

b/ McIntosh - storage season and harvest day - 1984/85; Sep. 19; storage duration at 3°C - 202 days; flesh firmness /kgf/ at harvest - 5,8; titratable acids /mg malic/100g fw./ - 804

5 + 3	5,1	5,6χ	5,1	5,5χ	427	463	413	423	0	10cf	0	10cf
2 + 1	5,7	5,8	5,7	5,6	497	483	457	450	0	0	0	0
0 + 1	5,7	5,8	5,7	5,7	467	477	433	457	0	0	0	0
2 + 2	5,5	5,6	5,1	5,4χ	440	433	397	407	0	10cf	c	5cf

θ/ McIntosh - storage season and harvest day - 1984/85, Sep. 27; storage duration at 3°C - 194 days; flesh firmness /kgf/ at harvest - 5,5; titratable acids /mg malic/100g fw./ - 666

5 + 3	5,3	5,6χ	4,9	4,8	407	420	353	397	0	0	10cf	10cf
2 + 1	5,7	5,7	5,8	5,2	430	460	413	420	0	0	15cf	0
0 + 1	5,4	5,6χ	5,5	5,3	437	447	403	400	0	15cf	0	0
2 + 2	5,2	5,6χ	4,9	4,6	393	467	373	377	0	0	0	0
N	3,7		-	-	240		-	-	90cf		0	

Notice: fb - flesh browning
cf - core flush
ss - superficial scald

χ = means that differences were statistically significant

Table 3.

The effect of low ethylene controlled atmosphere storage on Spartan, Golden Delicious and Jonathan apples

Spartan - storage season and harvest day - 1984/85, Sep.26; storage duration at 3°C - 202 days; flesh firmness /kgf/ at harvest - 6,2; titratable acids /mg malic/100g fw./ - 571

Storage atmosphere % CO_2 + % O_2	Flesh firmness after storage				Titratable acids after storage				Physiological disorders % of fruits			
	3°C		6-7 days in : 18°C		3°C		6-7 days in : 18°C		3°C		6-7 days in : 18°C	
	HE	LE	HE	LE	HE	LE	HE	LE	HE	LE	nE	LE
1	2	3	4	5	6	7	8	9	10	11	12	13
5 + 3	5,40	5,80 x	5,03	5,40 x	365	371	325	343	0	0	10 cf	20 cf
0 + 3	4,85	4,83	4,94	4,72	309	339	290	295	50 cf	55 cf	85 cf	60 cf
2 + 1	6,17	6,21	5,81	5,85	390	370	406	340	0	5 id	0	0
0 + 1	6,01	5,99	5,81	5,79	372	370	358	358	0	c	0	0
2 + 2	5,17	5,22	5,08	5,53	339	368	330	340	0	5 cf	0	5 cf
N									30 cf		100 cf	

Spartan - storage season and harvest day - 1984/85; Oct. 4; storage duration at 3°C - 194 days; flesh firmness /kgf/ at harvest - 5,9; titratable acids /mg malic/100g fw./ - 532

5 + 3	5,35	5,67 x	5,18	5,10	335	333	286	311	0	0	30 cf	0
0 + 3	4,81	4,88	4,83	4,80	287	279	280	268	30 cf	35 cf	75 cf	55 cf
2 + 1	5,99	6,03	5,78	5,76	335	355	305	326	0	5 id	0	0
0 + 1	5,71	6,01	5,62	5,61	350	355	333	331	0	0	0	5 cf
2 + 2	5,22	5,01	5,40	5,14	343	305	286	296	5 cf	0	0	0
N									40 cf			

Golden Del. - storage season and harvest day - 1982/83; Sep. 28; storage duration at 3°C - 220 days; flesh firmness /kgf/ at harvest - 8,7; titratable acids /mg malic/100g fw./ - 641

5 + 3	7,2	7,7 x	6,7	7,0	502	518	-	-	0	0	0	0
2 + 2	7,4	7,4	7,0	7,6	502	504	-	-	0	0	0	0
1 + 1	7,6	7,5	7,3	7,5	525	561	-	-	0	0	0	0

Golden Del. - storage season and harvest day - 1982/83; Oct. 7; storage duration at 3°C - 230 days, flesh firmness /kgf/ at harvest - 6,3; titratable acids /mg malic/100g fw./ - 681

5 + 3	6,5	7,2 x	6,8	7,2	494	500	-	-	e	e	e	e
2 + 2	6,9	7,5 x	7,1	7,4	482	484	-	-	0	0	0	0
1 + 1	7,3	7,4	7,3	7,7	538	543	-	-	0	0	0	0

Cont.table 3.

Golden Del. - storage season and harvest day - 1983/84; Sep. 30; storage duration at 3°C - 207 days, flesh firmness /kgf/ at harvest - 7,3; titratable acids /mg malic/100g fw./ - 472

1	2	3	4	5	6	7	8	9	10	11	12	13
5 + 3	7,1	7,6*	6,8	7,2*	377	391	204	210	0	0	0	0
2 + 2	6,5	6,8	5,4	6,7	336	415	198	216	0	0	0	0
1 + 1	7,2	7,2	6,7	7,0	399	392	225	237	0	0	0	0

Jonathan - storage season and harvest day - 1983/84; Sep. 26; storage duration at 3°C - 211 days; flesh firmness /kgf/ at harvest - 7,0; titratable acids /mg malic/100g fw./ - 703

5 + 3	6,0	7,8*	4,7	5,4*	534	531	285	267	0	0	0	0
2 + 2	5,1	5,7*	4,6	4,6	469	506	274	284	0	0	0	0
1 + 1	6,1	7,0*	4,8	5,1*	517	516	284	307	0	0	0	0

Notice: cf - core flush
id - intern. CO_2 damage

X = means that differences were statistically significant

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