Report

Cutting Performance of the Waterjet Cutting System of Digital Control

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VERTROUWELIJK

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1. Introduction

As a result of a contact of G. v. Vilsteren with Mr. H.Montastruc of Digital Control, Digital Control was willing to demonstrate their Waterjet cutter on ATO. This waterjet cutting system was demonstrated on 3th of February, by Mr. Laurant Demaret of Digital Control.

Up to this moment, the application of waterjet cutting systems in the food industry is infrequent. In the bakery industry few of this waterjet cutting systems are in use. This demonstration of the waterjet cutter was a chance to compare the cutting performance of this system with other cutting systems. In this report the results of this comparison are presented.

2. Aim

In this small study the results of the waterjet cutter will be compared with other, traditional cutting systems.

3. Materials and methods

3.1 Products

In Table 1, the products and cutting systems which have been tested are summarised.

Tabel 1 Products and cutting systems which have been tested

Product	Cutting systems	
	Waterjet	Other device(s)
Apple (70/80, Netherlands, unpeeled)	6*6 mm (core removed)	1. Urschel 6*9.6, 2. Hällde 6*6 mm
Lettuce (Spain)	adapter	1. Glastra Ideaal, 2. Not cutted (whole leaves)
Mushroom (Agaricus Bisporus L., Netherlands)	slices with adapter	Hällde
Bell pepper, red (California Rojo calibre G, 70-90 mm, Spain)	strips, 6 mm	Urschel 6*9.6
Tomato (Claudia, Can, Spain)	barely	nv.t
Cucumber (Pandal, Spain)	slices, 4 mm	Hällde slices, 4mm
Kiwi	slices, 2 mm	Hällde slices, 2 mm
Meat sausage	shaping	

3.2 Cutting devices and methods

1. Water jet cutter (Fig. 1), DIGITAL Control (Route de Lavaur ZA de Marignac BP 19-31850 Montrabe (Toulouse) France, tel 00 33 561 845704 (For the bakery industry in the Netherlands: Samach Centrumbv, Grauwe polder 32, 4876 NB, Postbus 213, 4870 AE, Etten Leur (076 5022600, Fax 076-5015859, Sales manager Rene Haddeman).

Specifications:
Connection 3/4 " and 3 bar tapwater, Electric power: 380 V, 32 Ampere.
Sizes: area 2,0*2,0 m en 2,0 m high. Waterdruk 3500 bar.

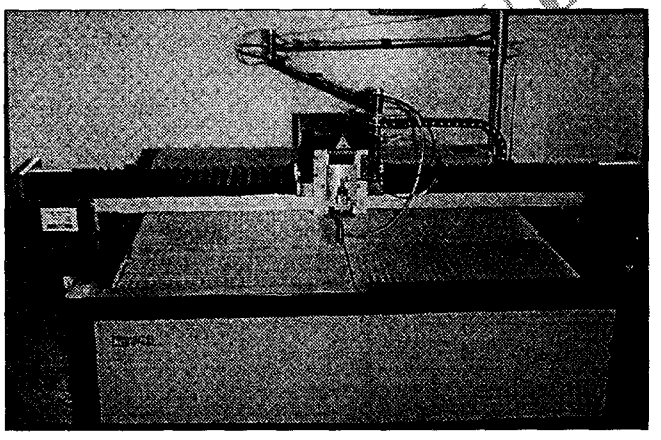

Fig. 1 Waterjet cutting system of Digital Contol

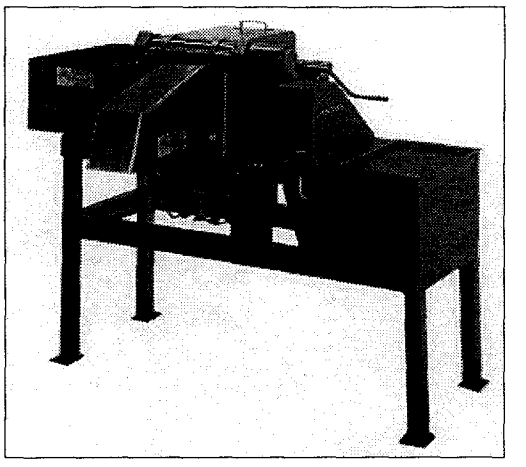

Fig. 2 Urschel GK-A cutting machine

2. Urschel GK-A cutter (Fig. 2), fitted to cut dices, strips and slices

3. Hällde
Fitted to cut dices and slices

4. Glastra Ideaal
Cutting to slices

3.3 Packaging and storage

foils used: PA 160 (air)
PVDC/OPP with a gas atmosphere of 50% CO_2, 20% O_2 en 20%N_2

Judgement (colour, smell, spots and total appearance) after 6 days of storage at 8°C
Measurement of atmosphere in packages after 3 and 6 days of storage at 8°C.
In addidion all cuttted products have been stored two days at 10 and 20°C in plastic boxes, covered with plastic lids.

3.4 Measuring methods

concentrations of gasses
Monitoring of CO_2, O_2 en N_2, in the packages during 0 and 5 days of storage.

Wound tissue
The quantity of wound tissue as a result of the cutting operation, is measured by means of the electric conductivity and the absorption at 258 nm of the liquid, the tissue is rinsed with. From the cut tissue in study, 100 g is combined with 100 ml of a 0.4M mannitol solution (Parkin, 1990) in a jar of 370 ml and shaken (Salm en Kipp shaking machine, level 8) during 10 min. Thereafter the rinsing liquid is centrifuged during 20 min (speed 6) and filtered over folded paper. Thereafter there is filtered with a microfilter of 40µ. After this filtration the electric conductivity is measured.

Respiration rate
From each sample the respiration of the vegetables is measured four times. For the measurements have been taken: 130 g of apple, 100g of Lettuce, 130 g of mushrooms and 140 g of bell pepper. The measurements took one hour except the measurements of mushrooms. Because of the high respiration rate of mushrooms, half an hour of measurement was sufficient.
The respiration rate was measured both as O_2 consumption and as CO_2 production and expressed as µmol/kg.s. O_2 consumption and CO_2 production, measured with a Chrompack CP2002 gaschromatograph.

Total count and pseudomonaceae
From each sample three quantities of 15 g have been taken and extracted in a physiologic salt solution with a stomacher. From this extraction dilutions were made. The media used were: Plate Count Agar (Oxoid CM 325) to determine "Total count", and Pseudomonas agar(Oxoid CM 559) with Pseudomonas C-F-C selective supplement (Oxoid SR 103 E) to determine Pseudomonaceae. The plates were incubated for 3 days at 20°C.

Low Temperature Scanning Electron Microscope and Cryofixation
Specimens were mounted on an aluminium stub with a thin film of Tissue Tec (Wallpaper glue). The sice of each specimen were painted with conductive solverpaint to reduce charging. The cutsurface of the specimen is carfully dryed with a tissue to adsorb most of the part of water what is left after cutting. The samples were frozen by immersion (plunge cooling) in NitrogenSlush (60K) of a Biorad E7400 Cryogenic Preparation System. The frozen stubs wre than transfered under vacuum conditions to the preparation chamber, were suface ice was etched by conductiveheating at about 180K for 10 minutes. After sputtering with Gold for 2 minutes at 9.33 Pa and 20mA current, the frozen specimens were transferred to a phillips PSEM 515 wich was been modified with a cryostat to maintain a specimen temperatuur at 110K. The photographs were taken at 10kVaccelarating voltage using Kodak T-max B/W film

4. Results

4.1 Visual judgement during and immediately after cutting

Apple

Fig. 3 Supporting system for apples on the waterjet cutting system

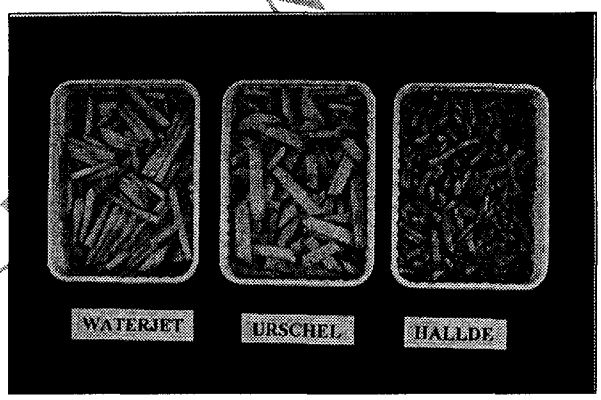

Fig. 4 Apple strips cut by the waterjet, Urschel and Hällde cutting system

To be able to cut the apples on the waterjet cutter a device was made as can be seen in Fig. 3. With the waterjet cutter strips were made as can be seen in Fig. 4. Looking in more detail in Fig. 4 it can be seen that the first cm, the waterjet cutter is cutting very well, with a smooth surface. But after a penetration of two centimetres into the product, the waterjet diverges which results in bruising the apple tissue. In Fig. 4 this can be recognised in a brown colouring in that part of the apples.
From Fig. 4 it can be seen that the Urschel cuts the strips with a kind of marble pattern. This points to cracks which will be the result of stresses in the product during the cutting operation. From Fig 4 it can also be seen that the Hällde is damaging the apples most of the cutting machines.

Lettuce

To be able to cut the lettuce by the waterjet cutter a device was made as can be seen in Fig. 5.

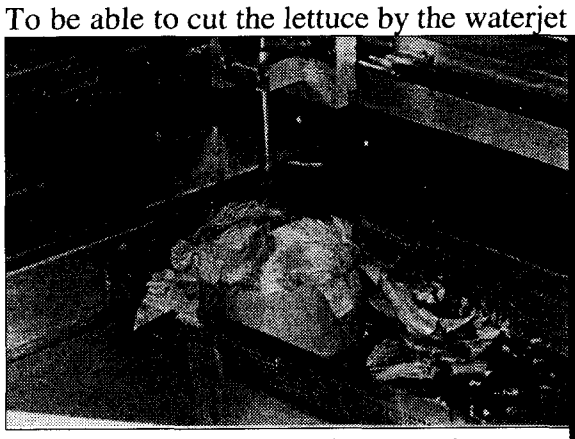

Fig. 5 Supporting system for lettuce on the waterjet cutting system

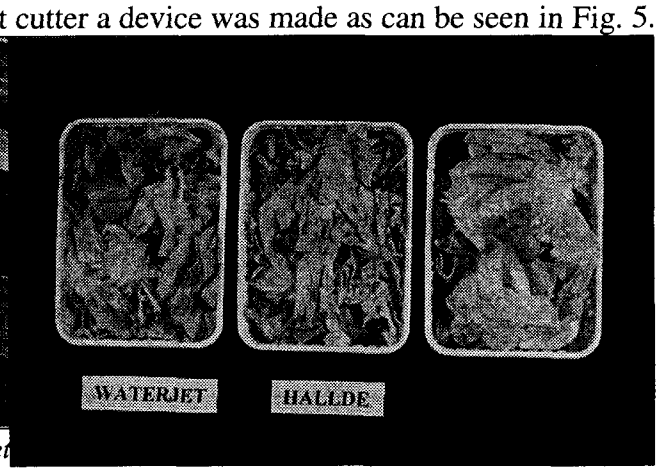

Fig. 6 Lettuce cut by the waterjet, Hällde cutting system and whole leaves of lettuce

Immediately after cutting, no differences between the lettuce cut by the Waterjet and by the Glastra Ideaal can be seen (Fig. 6).

Mushroom
Also for the mushrooms it was necessary to use a support to direct the mushrooms to the waterjet. By this way slices were performed. The Hällde cut the mushrooms at random and for that reason, the slices were not good. Cutting mushroom, the waterjet diverges at some distance of the orifice of nozzle and destroyed some tissue.
In general the mushrooms cut by the Hällde were more crumbled than the mushrooms cut by the waterjet

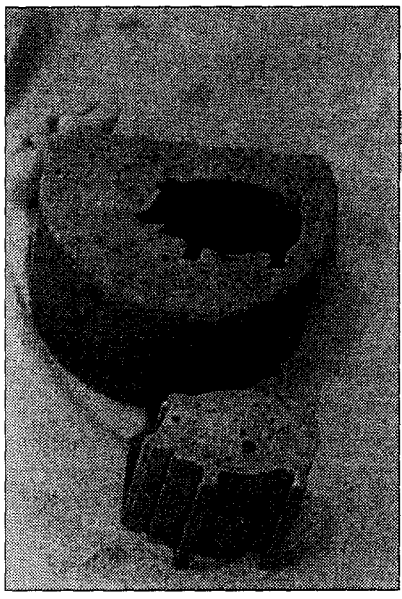

Fig. 7 The flexibility in shape of the waterjet cutting system

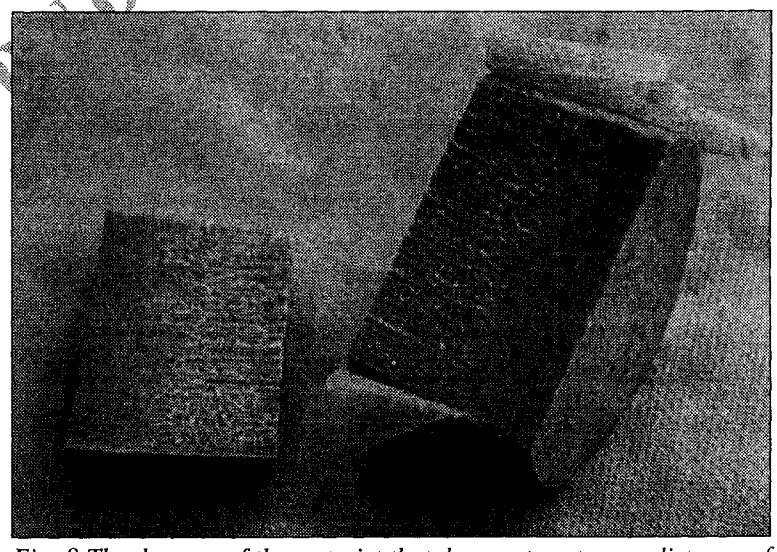

Fig. 8 The damage of the waterjet that devergates at some distance of the orifice of the nozzle

Red bell pepper
Also for the paprika a support device was used with the waterjet cutter. The snit of the waterjet cuttings are much more coarse than the snit from the Urschel (once 6 mm, compared to 6 mm x 9,6 mm).

Cucumber
The slices cucumber of 4 mm,, cut by the waterjet cut cucumber show a more rough surface than the slices cut by the Hällde. Comparable with the mushrooms and apple, the pattern of the waterjet can be seen on the cutting surface.

Kiwi
The slices kiwi of 2 mm, cut by the waterjet show holes. Because of the tissue of the kiwi is soft and the tissue is sucked away by the vacuum caused by the waterjet. For this reason a waterjet is not fitted for products with soft tissues.

Meat sausage
The sausage is only cut by the waterjet cutter. From Fig. 7, the advantage of the waterjet cutter is to see. It is very easy to make all kinds of shapes with this cutter. From Fig. 8, it can be seen very well the effect of the divergation of the jet after some distance from the orifice of the nozzle.

4.2 Visual judgement after storage
Apple
The results of the judgement after 6 days of storage at 8 °C are summarised in Table 2.

Table 2. The judgements of the products, cutted by the cutting devices and packed in air and gas (50%CO_2, 20%O_2 and 20%N_2) and stored 6 days at 8°C

Product	Cutting device	Package material	Judgement after 6 days of storage (0=good, 5=bad)			
			colour	smell	spots	total
Apple	waterjet	Pa-160 air	*	*	*	*
	Urschel		*	*	*	*
	Hällde		*	*	*	*
	Waterjet	PVDC gas	*	*	*	*
	Urschel		*	*	*	*
	Hällde		*	*	*	*
Letuce	waterjet	Pa-160 air	3.0	0.0	0.0	1.0
	Glastra		4.0	0.0	0.0	1.0
	whole leaves		5.0	0.0	0.0	1.0
	Waterjet	PVDC gas	0.0	0.0	0.0	0.0
	Glastr		0.0	1.0	0.0	1.0
	whole leaves		0.0	0.0	0.0	0.0
Mushroom	waterjet	Pa-160 air	5.0	0.0	0.0	1.0
	Hällde		4.0	0.0	0.0	1.0
	Waterjet	PVDC gas	3.8	0.8	0.0	0.8
	Hällde		4.0	1.0	0.0	1.0

* too bad to judge

From the packed apple strips, stored three days at 8°C in air and in high O_2 and CO_2, the results of the cutting devices are relative the same as judged immediately after cutting. In addition, differences between the air and gas packed apple strips cannot be seen.

The results of the judgement after two days of storage at 10 and 20°c are summarised in Table 3.

After two days of storage at 10 and 20°C in the plastic boxes, the results of the cutting devices are relative the same as directly after the cutting. In general the Urschel and Waterjet have the same gradation of brown colouring. The strips from the waterjet shows more brown colouring

in the under part of the strips, while the Urschel strips show more brown cracks. The apple strips stored at 20°C are a little more brown than the strips stored at 10°C.

Table 3. Judgements of the products cutted by the mentioned cutting systems after storage of two days in plastic boxes.

Product	Cutting device	Temp (°C)	Judgement
Apple	Waterjet	10	Best sample. Brown at more distance from nozzle 1)
		20	More brown 3)
	Urschel	10	Between previous two samples 2)
		20	More brown than from waterjet 4)
	Hällde	10	Very brown 5)
		20	Very, very brown 6)
Letuce	Waterjet	10	More brown cutting surfaces than Glastr 2)
		20	More brown than 10°C sample 6)
	Glastra	10	Better than waterjet 10°C 3?)
		20	A little less than previous sample 4)
	Whole	10	Less brown edges, some brown parts 1)
	leaves	20	More brown than 10°C sample 5)
Mushroom	Waterjet	10	Straight slices, some jet profiles
		20	Some curling slices, a little bit more gray than 10°C
	Hällde	10	Messy slices, colour comparable with waterjet 10°C
		20	Messy slices, colour comparable with waterjet 20°C
Red bell pepper	Waterjet	10	Coarse parts, more light than Urschel 10°C,
		20	Less orange/ red than 10°C
	Urschel	10	Looks good, but irregular cut
		20	More dark, brown? Than 10°C
Cucumber	Waterjet	10	Good slices, green surface
		20	Slices benting and surfaces yellow
	Hällde	10	Good slices
		20	More yellow than 10°C
Kiwi	Hällde	10	Firm green slices
		20	Less firm, less fresh, more gray

1-6) order of quality judgement (1=best, 6=most worse)

Lettuce

The Lettuce, gas packed doesn't show any brown colour. So from these samples no difference between the effect of the cutting devices can be seen. In the air packed lettuce, the lettuce both cut with the waterjet and with the Ideaal, have brown coloured cutting areas. Because the waterjet cut parts are larger, the overall look is better. The waterjet lettuce in air packed (PA160) looks

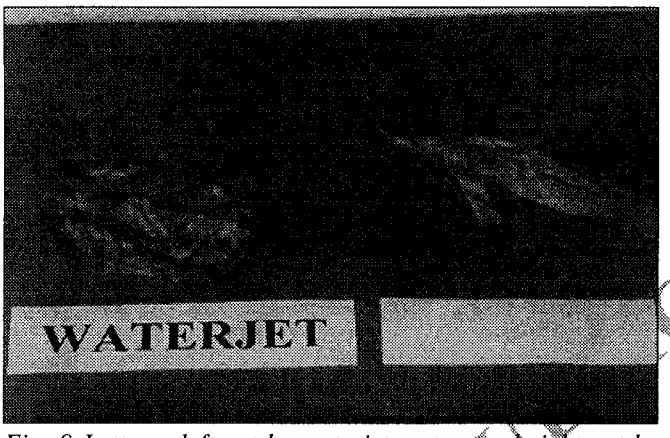

Fig. 9 Lettuce, left cut by waterjet system and right cut by Glastra Ideaal

like it has less colour.

From the lettuce, stored two days at 10 and 20°C in the plastic boxes, the results of the waterjet cutter are worse than from the Glastra Ideaal and the whole leaves. The cut parts from the water jet cutter have more brown cutting surfaces than the lettuce cut by the Glastra Ideaal as can be seen in Fig. 9 (dark spots are brown coloured).

Mushroom
Both for the gas packed as for the air packed mushrooms, not too much differences in colour between the two cutting devices can be seen.
From the mushrooms stored two days, no differences can be seen between the results of the two cutting devices.

Red bell pepper
The red bell pepper has not been packed in foils and stored at 8°C.
From the results of the storage at 10 and 20°C during 2 days in the plastic boxes it appears that the waterjet cut paprika's looks more light than the paprika cut with the Urschel. The more dark colour of the Urschel cut bell pepper is caused by more damaged tissue compared with the waterjet cut bell pepper. The red bell pepper, cut with the Urschel were more damaged, especially by the transport over the first knife of 9,6 mm.

Cucumber
Differences in quality between the slices cut by the waterjet or by the Hällde can not be seen.

4.3 Effects of cutting device on atmosphere in packaged products
In Table 4 the results of the measurements of the atmosphere in the packages are presented. From these data no differences in effect of devices on the atmosphere can be seen, except for the lettuce in the impermeable PVDC foil. The concentration of CO_2 in the package with lettuce cut with the Glastra is significant higher than in the packages with whole leaves and with the lettuce cut by the waterjet. From this it can be concluded that the respiration of the lettuce cut by the Glastra is higher than from the lettuce cut by the waterjet. This result is not what should be expected compared to the discolriation as shown in Fig. 9. The more discoloured cutsurface of the lettuce cut with the waterjet implies more respiration of the lettuce in the package and so a higher CO_2 conctentration in the package. An explanation of this contradictory effect can not be given. The data of the atmosphere in packages with mushrooms after 6 days of storage, don't look consistent.

Table 4. The O_2 and CO_2 content in the packages filled with apple, lettuce and mushroom, cut by the devices and packed in air and gas (50%CO_2, 20%O_2 and 20%N_2) and stored 6 days at 8°C

Product	Cutting device	Package material	O_2 and CO_2 content in packages after 3 days and 6 days			
			O_2	CO_2	O_2	CO_2
Apple	waterjet	Pa-160 air	14.7	9.4	14.3	10.1
	Urschel		13.2	11.6	11.3	14.3
	Hällde		6.0	9.7	10.1	20.2
	Waterjet	PVDC gas	11.8	55.3	7.7	40.9
	Urschel		5.6	54.0	9.4	46.1
	Hällde		7.0	56.3	4.9	66.0
Lettuce	waterjet	Pa-160 air	18.4	4.2	18.4	3.9
	Glastra		18.0	4.7	17.5	5.0
	whole leaves		19.2	3.4	18.2	4.2
	Waterjet	PVDC gas	22.9	34.0	13.9	36.1
	Glastr		34.2	52.0	19.5	58.4
	whole leaves		22.7	38.4	18.2	33.0
Mushroom	waterjet	Pa-160 air	6.5	16.8	2.1	22.7
	Hällde		9.7	13.9	21.5	0.3
	Waterjet	PVDC gas	4.2	43.9	17.0	6.3
	Hällde		3.0	65.1	7.1	30.0

4.4 Effect of cutting device on cellulair level

Apple

The effect of the cutting devices on the cells of the product can be seen by the pictures made of the SEM images, presented in Fig.10, 11 and 12 of respectively the waterjet, the Urschel and the Hällde. From these SEM pictures it appears that the Hällde (Fig. 12), damages the apple tissue most. Especially the skin of the apple dices, cut by the Hällde is cleaved. The skin of the apple parts, cut by the other two methods (Fig. 10 and 11), are not damaged. The cells, lying directly under the the skin of the apple dices, cut by the Urschel (Fig. 11), are more open and looks better cut, compared to the dices cut by the water jet cutter (Fig. 10).

Lettuce

From the SEM pictures it looks like there are not too much differences between the waterjet and the Glastra. In both cases the cells looks flattened by the cutting treatment. In case of the waterjet cutter it looks like the cells are more flattened than from the tissue cut by the Glastra, as can be seen in Fig. 13 and 14.

Mushroom

From the SEM pictures (Fig. 15 and 16) not too much differences between the waterjet and the Hällde can be seen. It looks like the mushroom cutting surfaces of the Hällde are a little more open and have more profile than of the mushroom cutting surfaces of the

Red bell pepper

From the SEM pictures (Fig 17 and 18) the an obvious difference in effect of the waterjet and Urschel on the tissue of the red bell pepper, is to see. The waterjet causes a more frayed cutting area than the Urschel. However from the outlook of the two days stored red bell peppers, the Urschel cut strips looked more damaged. Probably this is caused by the damage of the first cut of the Urschel parallel to the plane of the halved red bell pepper.

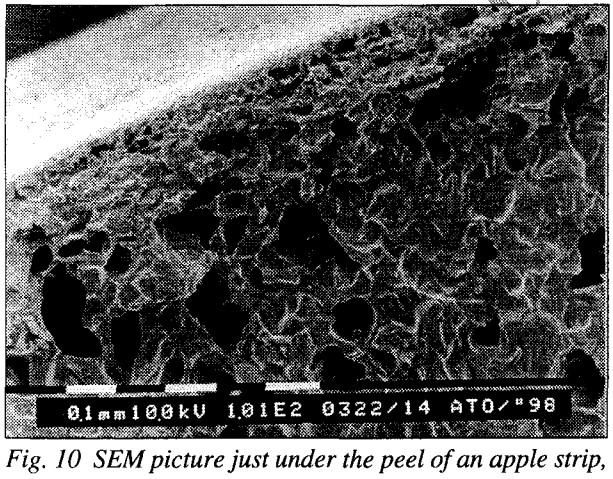

Fig. 10 SEM picture just under the peel of an apple strip, cut by the waterjet cutting system

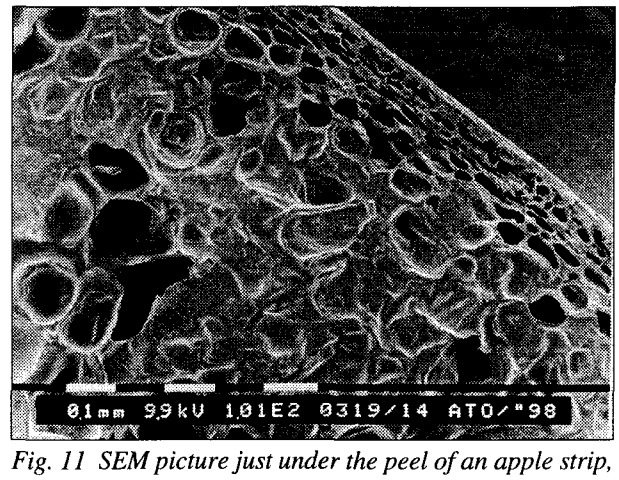

Fig. 11 SEM picture just under the peel of an apple strip, cut by the Urschel cutting system

4.5 Respiration activity

From the Fig. 19 and 20 respectively the O_2 uptake and the CO_2 production can be seen. These figures don't show to much differences between the products cut by the waterjet and the other cutting systems. This is the case for all the four tested products. The more damage in the tissue by the cutting treatment, the more respiration activity can be expected. So from this measurements one should conclude that there is not too much difference in the damage caused by the the compared cutting systems.

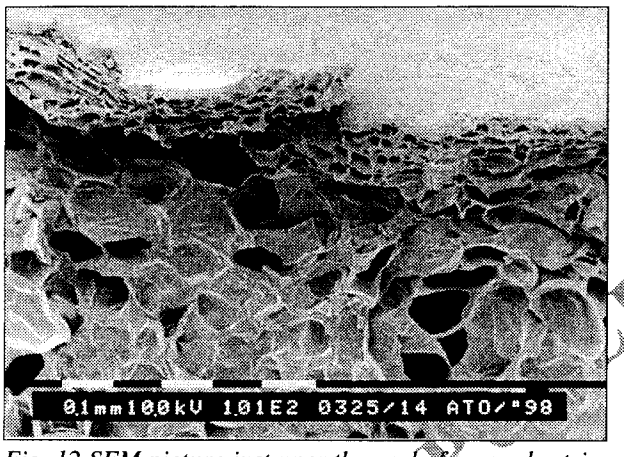

Fig. 12 SEM picture just uner the peel of an apple strip, cut by the Hällde cutting system.

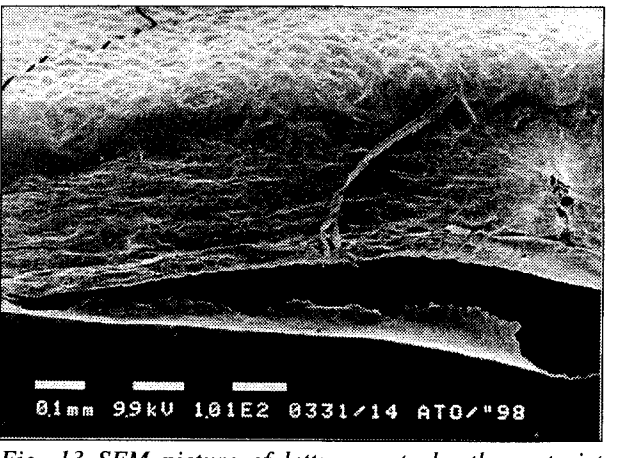

Fig. 13 SEM picture of lettuce, cut by the waterjet cutting system

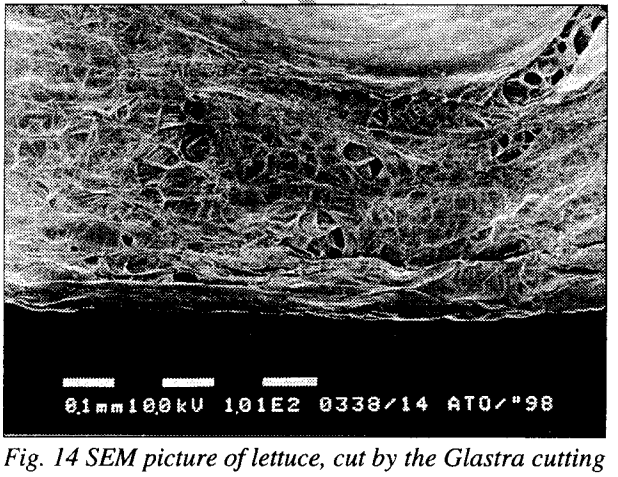

Fig. 14 SEM picture of lettuce, cut by the Glastra cutting system

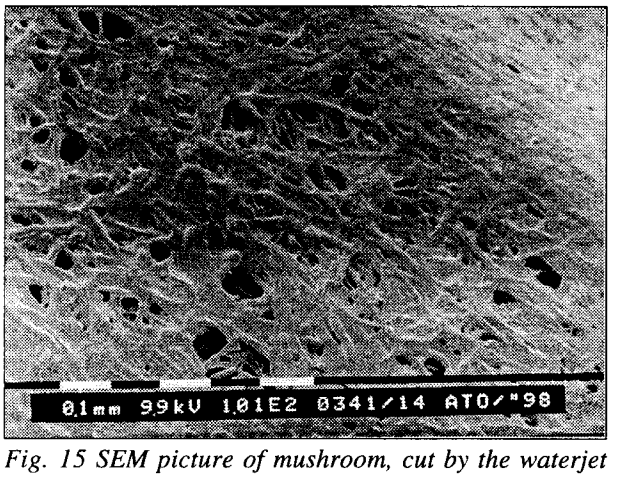

Fig. 15 SEM picture of mushroom, cut by the waterjet cutting system

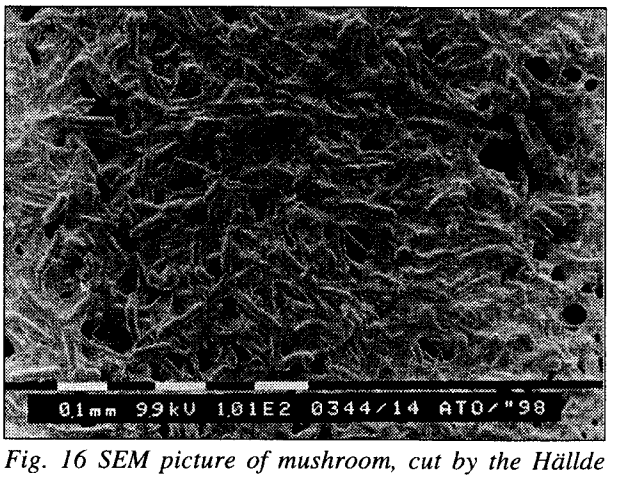

Fig. 16 SEM picture of mushroom, cut by the Hällde cutting system

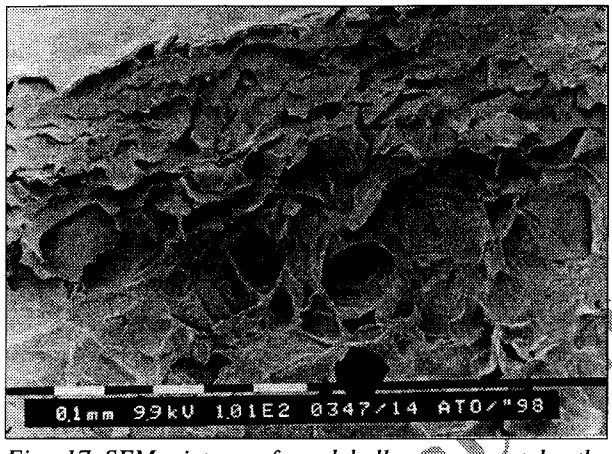

Fig. 17 SEM picture of red bell pepper, cut by the waterjet cutting system

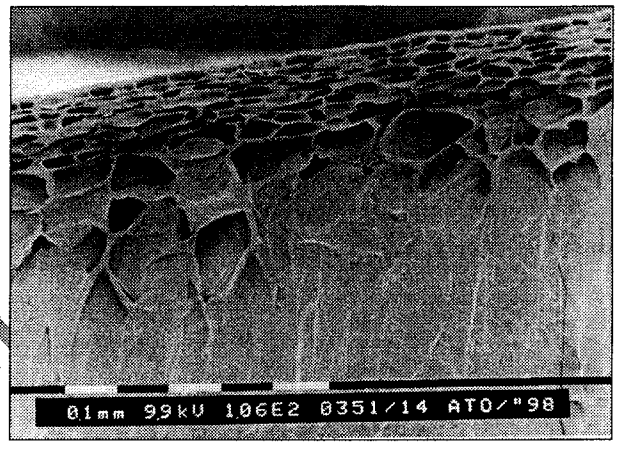

Fig. 18 SEM picture of red bell pepper, cut by the Urschel cutting system

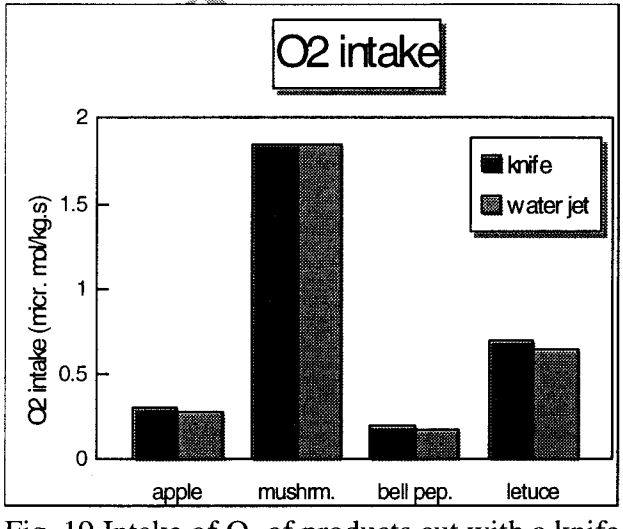

Fig. 19 Intake of O_2 of products cut with a knife device and with a water jet

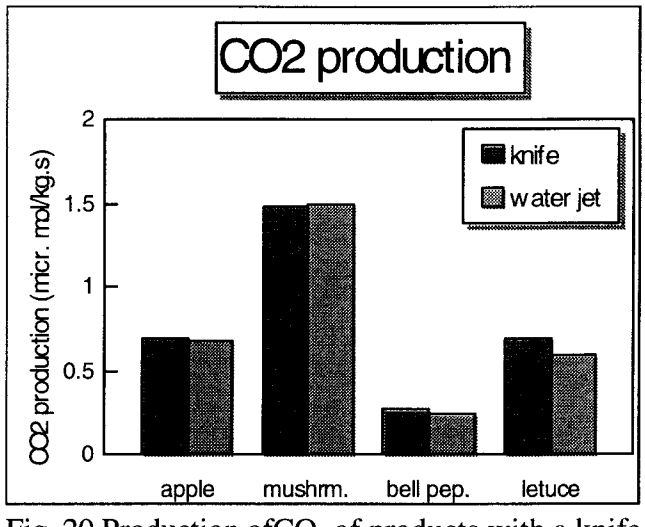

Fig. 20 Production ofCO_2 of products with a knife and with a water jet.

4.6 Woundtissue

In table 5, the results of the measurements of the wound tissue, by means of the electric conductivity is shown. From this Table it can be seen, that there is a dependancy of the cutting method and the electric conductivity measured. However, it is not always possible to compare the results, because of the different sizes of the cubes or strips. Only the sizes of the cucumber slices are the same for both cutting devices. From the cucumber it appeares, that the waterjet causes more wound tissue than the Hällde. From Table 5 it also appears that the most small particles result in the highest electric conductivity. Only for apple, the smaller sizes as a result of the waterjet system, have the same conductivity as the more course particles cut by the Urschel.

Table 5. Electric conductivity (mSiemens) in rinsing liquid, 1:1 met product

product	waterjet	cutting device with a knive		
		Urschel	Hallde	Ideaal
Apple	0.63 2) 0.59	0.64 1) 0.63	0.97 3) 1.01	
Lettuce	0.54 1) 0.50			0.61 2) 0.62
Mushroom	1.07 1) 1.07		1.13 2) 1.09	
Red bell pepper	0.85 1) 0.86	1.25 2) 1.12		
Cucumber	0.91 4) 0.91		0.55 4) 0.50	

1) fine, 2) more fine, 3) most fine, 4) 4mm

4.7 Total count and pseudomonaceae

The results of total count and Pseudomonaceae, are summarised in Table 6.

Tabel 6 Bacterial count on letuce and mushroom, dependent on cutting device and storage time

Product	Cutting device	cage time	Total count*10^8	Pseudomonas*10^8
Lettuce	Waterjet Glastra	3 days 8°C „	1.1 and 1.2 1.0 and 1.0	1.1 and 1.0 0.8 and 1.1
Mushroom	waterjet Hällde waterjet Hällde	3 days 8°C „ 6 days 8°C „	>1, >1 and >1 >1,>1 and 3.0 13 and 11 22 and 42	>1,>1 and >1 >1, >1 and >1 9.5 and 12 18 and 36

Table 6 shows that in relation to the counts after 3 days, the dilutions were not good and comparison is possible. The mushrooms stored 6 days in air, show a higher total count and Pseudomonaceae on the mushrooms cut by the Hälde. However this difference is too small to come to conclusions. From the Lettuce no differences can be seen. In addition after 6 days of storage, the product was in such a bad condition that no conclusions can be made.

5. Conclusions

- The cutting performance of the waterjet is in general worse in comparison with the results of the Urschel and Glastra and better in relation to the Hällde. Restricted to the first two centimeters from the nozzle, the waterjet results in less damaged tissue than the Urschel. In particular this is to see on the apple strips. The strips cut with the Urschel, show a marble pattern which points to cracks which will be the result of stresses in the product during the cuttng operation. The first two centimeters of the apple strips, cut with the waterjet, show almost no discolouration.
- On a cellular level the Urschel shows the most regular cutting areas in relation to the waterjet and the Hällde or Glastra. However in several cases the cutting area as a result of the waterjet was comparable with the results of the Urschel.
- From the results of the respiration rate, wound tissue and microbial total count and psuedomonaceae, no conclusions can be made about the cutting performances of the cutting devices compared in this study.

References

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