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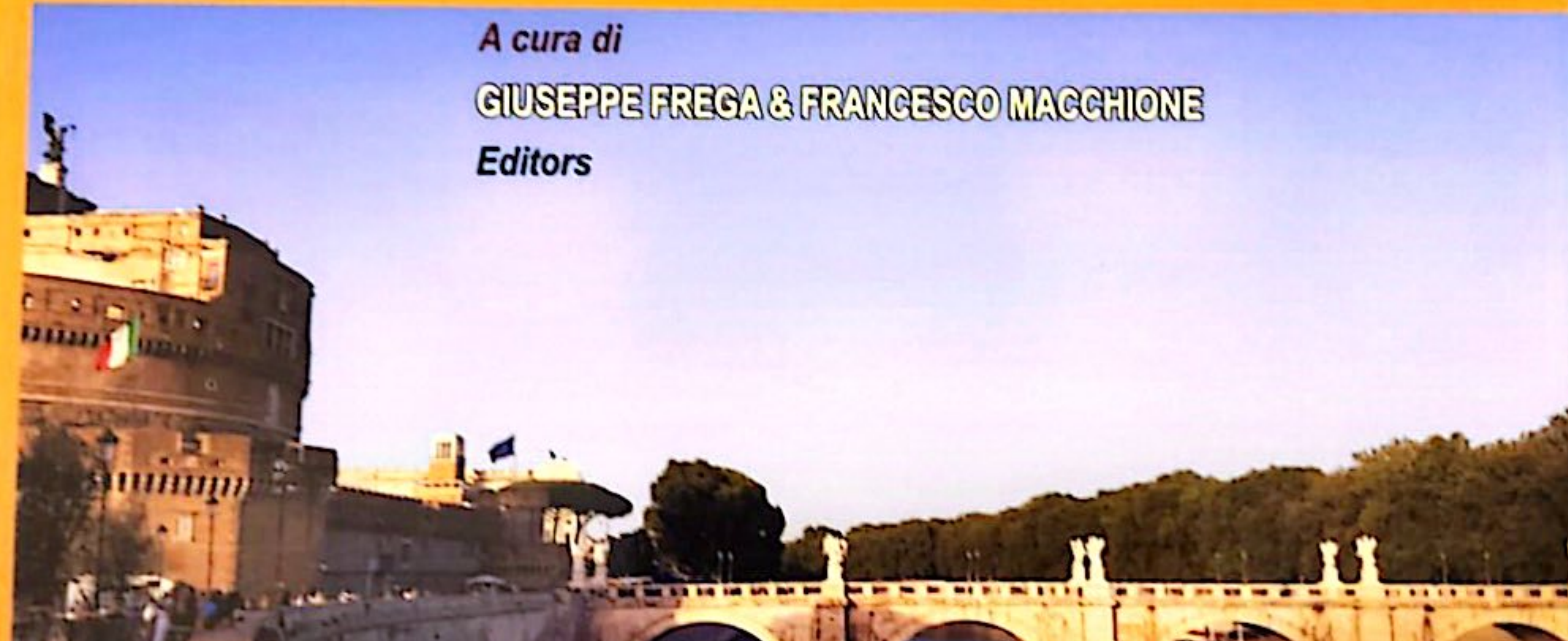

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PRELIMINARY ESTIMATION OF I AND IV RANGE WATER REQUIREMENTS IN AGRI-FOOD SYSTEMS

STIMA PRELIMINARE DEI FABBISOGNI IDRICI DEI MAGAZZINI DELLA FILIERA ORTOFRUTTICOLA DI I E IV GAMMA

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ABSTRACT ESTESO

L'industria dei prodotti ortofrutticoli freschi tagliati, che comprende sia la "I Gamma" (prodotti freschi minimamente lavorati) che la "IV Gamma" (frutta e verdura pronte al consumo), è un settore in rapida espansione, trainato dalla domanda dei consumatori di praticità e alimentazione sana. I prodotti di I Gamma comportano una lavorazione minima, come il lavaggio, la cernita e un semplice confezionamento di prodotti interi o leggermente preparati, come insalate in busta o carote intere pelate. Questi articoli mantengono gran parte del loro stato naturale e richiedono ulteriore preparazione da parte del consumatore. Al contrario, i prodotti di IV Gamma sono completamente lavati, tagliati e spesso miscelati, pronti per il consumo immediato senza passaggi aggiuntivi. Esempi includono insalate di frutta pre-porzionate, bastoncini di verdura con salse o mix per soffritti. Questa industria si affida pesantemente a sofisticate tecnologie di lavorazione per garantire la freschezza, la sicurezza e una maggiore durata di conservazione del prodotto, inclusi l'imballaggio in atmosfera controllata e rigorosi protocolli igienici. L'imballaggio stesso è fondamentale, progettato per mantenere la qualità, prevenire il deterioramento e fornire informazioni chiare al consumatore. Poiché gli stili di vita diventano più frenetici, si prevede che il mercato per queste opzioni convenienti e salutari continuerà la sua solida crescita.

Il consumo idrico di questa industria è decisamente elevato. Nonostante ciò, in letteratura tecnica non si trovano contributi che consentano valutazioni di tale consumo.

Il presente articolo è pertanto destinato a illustrare i risultati preliminari volti alla quantificazione di questi consumi. L'approccio è quello di cercare di legare il consumo idrico alla quantità di prodotto immessa sul mercato, in modo da costruire uno strumento atto a prevedere i consumi.

La ricerca è stata condotta con approccio sperimentale. Sono stati misurati i consumi idrici insieme alle contestuali produzioni di alcune industrie di I e IV gamma. Sono stati pertanto ricavati degli indici sintetici di consumo.

L'articolo è strutturato nella seguente maniera: nel primo paragrafo vengono descritte le attività delle industrie di I e IV gamma. Successivamente si presentano l'approccio sperimentale e gli indici sintetici di consumo e vengono mostrati i primi risultati. Vengono infine delineate le conclusioni preliminari.

ABSTRACT

The processed fruit and vegetable sector, covering "I Range" (minimally processed) and "IV Range" (ready-to-eat) fruits and vegetables, is a fast-growing sector driven by consumer demand for convenience and health. I Range products involve basic processing like washing and simple packaging, while IV Range items are fully prepared for immediate consumption, requiring advanced processing and packaging for freshness and safety. Despite this industry's high water consumption, there's a lack of technical literature on its quantification. This paper aims to address this gap by presenting preliminary results, linking water use to product output. The research, conducted experimentally across several plants, derived synthetic water consumption indices to build a predictive tool, with initial findings detailed in the article.

1. Foreword

The fresh-cut produce industry, encompassing both "fresh-cut" (I Range) and "ready-to-eat" (IV Range) fruits and vegetables, is a rapidly expanding sector driven by consumer demand for convenience and healthy eating (e.g. Dias, 2011). I Range products involve minimal processing, such as washing, sorting, and simple packaging of whole or lightly prepared produce like bagged salads or whole peeled carrots. These items retain much of their natural state and require further preparation by the consumer. In contrast, IV Range products are fully washed, cut, and often mixed, ready for immediate consumption without any additional steps. Examples include pre-portioned fruit salads, vegetable sticks with dips, or stir-fry mixes. This industry relies heavily on sophisticated processing technologies to ensure product freshness, safety, and extended shelf life, including controlled atmosphere packaging and stringent hygiene protocols. The packaging itself is critical, designed to maintain quality, prevent spoilage, and provide clear information to the consumer. As lifestyles become busier, the market for these convenient, healthy options is expected to continue its robust growth.

The water consumption of this industry is significantly high. Despite this, there are no contributions in technical literature that allow for evaluations of such consumption.

This paper therefore aims to illustrate the preliminary results for quantifying this consumption. The approach is to try and link water consumption to the quantity of product released onto the market, in order to build a tool capable of predicting consumption.

The research was conducted using an experimental approach. Water consumption was measured alongside the contextual production volumes of several I and IV range processing plants. Therefore, synthetic consumption indices were derived.

The article is structured as follows: the first section describes the activities of I and IV range industries. Subsequently, the experimental approach and the synthetic consumption indices are presented, and the initial results are shown. Finally, the preliminary conclusions are outlined.

2. The AgriFood Systems of I and IV range

The processed fruit and vegetable sector, embracing both primary processed goods (fresh produce undergoing minimal alteration) and ready-to-serve items (pre-cut and prepared produce), stands as a substantial and swiftly developing segment within the food production landscape. This expansion is chiefly propelled by evolving consumer tastes favouring ease of use, nutritious selections, and diminished cooking duration. The operational breadth of these enterprises is diverse, necessitating rigorous oversight of numerous factors to guarantee product integrity, excellence, and prolonged viability.

"I Range operations" typically involve initial reception of raw agricultural materials, followed by a series of processes designed to maintain the product's near-natural state while enhancing its usability. These steps include meticulous "sorting and grading" to remove defective or unsuitable

Figure 1 - Washing line (I Range).
Fig. 1 - ***Linea di lavaggio (I Gamma).***

produce, ensuring uniformity and quality. Subsequently, produce undergoes thorough "washing and sanitizing" procedures, often utilizing chlorinated water or other approved sanitizers, to reduce microbial load. This is a critical step in mitigating potential foodborne pathogens. After washing, products like whole peeled carrots or trimmed broccoli florets might undergo "minimal cutting or trimming", followed by "packaging". Packaging materials for I Range products are typically designed to provide basic protection and visibility, without necessarily focusing on modified atmospheres, as further preparation by the consumer is expected.

"IV Range operations" are significantly more complex and resource-intensive, as the final product is intended for immediate consumption without further processing. Following initial reception and quality control, raw materials undergo more aggressive "washing and sanitizing" protocols. This is often followed by precise "cutting and dicing", utilizing specialized machinery to achieve uniform piece sizes and minimize cellular damage, which can accelerate spoilage. A crucial step for IV Range products is "de-watering" or "drying", often accomplished through centrifugation, to remove surface moisture that can promote microbial growth and reduce crispness.

Figure 2 - Washing line (IV Range).
Fig. 2 - *Linea di lavaggio (IV Gamma).*

The subsequent "packaging phase" for IV Range products is highly sophisticated, frequently involving "Modified Atmosphere Packaging (MAP)". This technique involves altering the gaseous composition within the package (e.g., reducing oxygen levels, increasing carbon dioxide) to slow down respiration rates, inhibit microbial growth, and preserve organoleptic qualities. The selection of appropriate packaging films with specific oxygen transmission rates is paramount. Throughout both I and IV Range processes, maintaining a strict "cold chain" is non-negotiable, with continuous temperature monitoring from harvest to final distribution to inhibit enzymatic degradation and microbial proliferation. "Traceability systems" are also integral, allowing for the precise tracking of produce from farm to fork, which is crucial for quality control and recall management. The high level of processing in IV Range products, in particular, necessitates rigorous "Hazard Analysis and Critical Control Point (HACCP)" plans and robust quality assurance programs to ensure microbiological safety and extend product shelf life while maintaining nutritional value and sensory attributes.

Water consumption by fresh-cut produce industry can be very high, in particular for the IV Range. As an example the Industry coded C in Table 1 has a yearly water consumption of about 300'000 m^3 per year that is the water needed by about 5'000 civil users.

For this reason can be interesting to evaluate such consumption and to understand its structure connected to the washed products.

Another important point to set up concerning the quality of the water. While in the I Range it is allowed to use almost "clean" water, in the IV Range sector is mandatorily to use potable water in order to ensure the safety of "ready to eat" products.

Table 1 - Industries considered in the study.
Tab. 1 - *Industrie considerate nello studio.*

N.	Code	Kind of Production	Total year Production (t)	Number of production days per year	Number of working days per year
1	A	I Range	6195	300	6.5
2	B	IV Range	35000	312	16
3	C	I Range	34894	312	5.43
4	D	IV Range	2500	305	10
5	E	I Range	4006	250	6.5

3. The experimental approach

Three I range industries and two IV range ones where considered for present study.

In all of them one week of measurements was conducted on a production line.

Discharge measurements were performed using TransPort PT900 clamp on flowmeters produced by GE Panametrics.

The first considered parameter is the "Specific Wash Water Consumption" named Ci.

The specific wash water consumption index for the ith product, expressed in liters of wash water used per kilogram of washed product, is a key metric for evaluating the efficiency of water use in a production process involving material washing, such as a food processing line. It therefore represents the ratio between the total volume of water used and the weight of the washed product, expressing how much water is required for each kilogram of product treated.

Such parameter is defined as follow:

$$C_i = Wi / Mi \tag{1}$$

in which

Wi – is the total water volume consumed for washing products (L);

Mi – is the total mass of washed products (kg).

Then the parameter is expressed as L/kg.

Low values of this index indicate high water efficiency, while high values indicate relatively high water consumption compared to the quantity of product washed. It is clear that this index should be understood primarily in comparative terms, to compare washing processes for different products, or to compare washing processes for the same product adopted by different industries

Factors that can influence this index include:

- Washing technology: More advanced systems (e.g., water recirculation or spraying) tend to reduce the index.
- Product type: Dirtier products (e.g., those with high soil content) or those with difficult-to-remove residues may require higher water volumes.
- System maintenance: Leaks or inefficiencies in the water network increase total water consumption.
- Process duration: Longer and less targeted washing processes increase the volume of water used.

Another important parameter is the Washing Line Productivity Rate Pi.

The washing line productivity rate is a key parameter for evaluating the efficiency of a process and, more generally, the productivity of the washing line. It expresses the quantity of product, expressed in kilograms, that a system can wash in an hour. It is a productivity indicator and measures how effectively a system or machine manages its workload.

Such parameter is defined as follow:

$$P_i = Mi / Ti \tag{2}$$

in which

Ti – is the total time of the washing cycle (h);

Then the parameter is expressed as kg/h.

Factors that can influence this index are:

- Machine type: The capacity and technologies used directly influence the result.
- Type of product washed: Weight, size, and degree of soiling can vary considerably.
- Wash cycle duration: A longer cycle reduces the number of kilograms washed per hour.
- Process efficiency: Factors such as energy consumption, water usage, and detergent dosage contribute to efficiency.
- Automation: More automated machines tend to ensure higher productivity.

A high index is desirable because it reduces costs per kilogram of product washed, increases workflow (defined as throughput), and improves company competitiveness.

Conversely, a low index could indicate process inefficiencies, such as undersized machinery or suboptimal resource management.

4. First Results

In present work we will describe only results concerning two kind of products, namely Radish for the I range and Vegetables for Salad for the IV Range.

As an example of obtained measurements, in Table 2 are reported measurements for the Radish washing line of industry A.

Table 2 - Measurements for Radish washing line in industry A.
Tab. 2 - *Misure per la linea di lavaggio del Ravanello per l'azienda A.*

Date	Start T	End T	P (kg)	W (L)	C_i [L/kg]	P_i [kg/h]
04/11/2024	09:15	11:57	3294.0	30479.8	9.25	1361.16
05/11/2024	15:30	16:13	712.0	11956.8	16.79	1655.81
06/11/2024	09:46	12:17	2482.0	34288.9	13.82	1074.46
07/11/2024	13:03	16:56	4044.0	56384.4	13.94	1145.61
08/11/2024	10:18	14:35	3660.0	63733.0	17.41	877.70
09/11/2024	11:21	14:53	2470.0	42070.7	17.03	743.98
				MEAN	**14.71**	**1143.12**
				MSR	**2.83**	**301.35**

It is interesting to point up the Ci and Pi parameters are usually in counterphase, while the washing discharge of the washing line is almost constant.

Such consideration suggests to optimize the P feeding of the washing line, maximizing it in order to reduce the water consumption.

In Table 3 synthetic results are showed for I Range (Radish Washing Line).

Table 3 - Mean results for radish washing line for I Range.
Tab. 3 - *Risultati medi per le linee di lavaggio del Ravanello nella I Gamma.*

N.	Code	Ci (L/kg)	Pi (kg/h)
1	A	14.71	1143.12
3	C	15.26	3308.23
5	E	4.66	927.44

It is interesting industry A and C show similar results in terms of Ci (about 15 L/kg) while industry E has a better performance namely a value of about 5 L/kg.

Obviously, such results can depend on the different degrees of cleanliness required from the market for I range products, and it requires a deeper understanding performing more measurements.

In Table 4 synthetic results are showed for the IV Range (Vegetables for Salad)

Table 4 - Mean results for Vegetables for Salad washing line for IV Range.
Tabella 4 - *Risultati medi per le linee di lavaggio dell'Insalata pronta nella IV Gamma.*

N.	Code	C_i (L/kg)	P_i (kg/h)
1	B	33.60	1595.31
3	D	39.40	188.06

Also such results require to be confirmed by subsequent measurements campaign.

It is interesting to point up such results permit to evaluate a "water footprint" of the production but also an energy footprint, while water should be usually pumped from wells, potabilized (IV Range) and at the end the wastewater should be treated before its discharge in the environment (Compton et Al., 2018).

5. Conclusions and future works

In the present paper preliminary results of a study devoted to characterize the water consumption by the fresh-cut produce industry, encompassing both "fresh-cut" (I Range) and "ready-to-eat" (IV Range) fruits and vegetables.

Three I range industries and two IV range ones where considered for present study. In all of them one week of measurements was conducted on a production line.

A specific wash water consumption index, namely C_i, for the ith product, expressed in Liters of wash water used per kilogram of washed product, is a key metric for evaluating the efficiency of water use in a production process involving material washing, such as a food processing line. It therefore represents the ratio between the total volume of water used and the weight of the washed product, expressing how much water is required for each kilogram of product treated.

Moreover, also a productivity index of the washing line was defined.

First obtained results permit to understand the entity of the water consumption by the fresh-cut vegetables industry. Such results can be used for dimensioning, as an example, industrial aqueducts starting from the hypothetical production of the industry.

Moreover, obtained results can be used also for suggesting optimization for the production cycle, while the consumption parameter and the productivity index seems to be in counterphase. Then maximizing the productivity of a washing line is possible also to minimize its water consumption.

Further measurements are required in order to better understand the effective water consumption. Actually, measurements are under development in other industries of I and IV range by our Research Group, as part of the Italian applied Research Project with Italia Ortofrutta: *Progetto di ricerca applicata per l'efficientamento dell'uso degli input nei magazzini delle Organizzazioni dei Produttori del settore ortofrutticolo – Linea 1: Razionalizzazione dell'uso dell'acqua nei magazzini di lavorazione.*

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