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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Effect of Suction Heads and Nutrient Solutions on Flow-Rates of Peristaltic Pumps Used in Hydroponics

Hidroponikte Kullanılan Peristaltik Pompaların Debisine Besin Çözeltilerinin ve Emme Yüksekliklerinin Etkisi

Cafer GENÇOĞLAN[1*], Serpil GENÇOĞLAN[2]

Abstract

To ensure the healthy growth of plants in hydroponics, it is crucial to determine the amount of nutrient solution that peristaltic pumps inject per unit time under various hydraulic conditions. The aim of this study is to test the effect of peristaltic pumps, suction heads and nutrient solutions on the flow-rate of the peristaltic pump. The tests of the flow-rate were conducted as aging and main test. Treatments consisted of 3 pumps (PP1, PP2 and PP3), 2 suction heads (30 (SH30) and 60 cm (SH60)) and 5 solutions (tap water (S1), stock A (S2), stock B (S3), nitric acid (HNO3) (S4) and potassium hydroxide (KOH) (S5)). In both tests, the volume of liquid pumped by the pumps for 2 minutes was determined and the volume-time relationship was utilized to calculate flow-rates. Aging tests showed that the new peristaltic pumps should be used in nutrition dosing after aging number was equal and greater than 5. All treatments had significant effect ($p<0.01$) on flow-rates. The mean flow-rates of pumps (PP1, PP2 and PP3) were found to be 102.0, 103.4 and 103.7 mL min^{-1}, respectively. The flow-rates of PP2 and PP3 are 1.36% and 1.67% greater than that's of PP1, and they could vary according to the pumps. Average flow rates for SH30 and SH60 were found as 103.6 and 102.5 mL min^{-1}, and flow rate decreased by 1.1% when the suction head increased from 30 to 60cm. The highest average flow-rate was obtained in tap water (S1=104.7 mL min^{-1}), while the lowest average flow rate (S5=101.2 mL min^{-1}) was found for Stock B. Flow rates of the S1, S2, S4 and S5 compared with the lowest flow-rate of solution (S3=101.2 mL min^{-1}) were found to be higher as 3.51%, 1.78%, 1.1% and 2.66%, respectively. The highest flow-rates changed between S1-S3, and the lowest ones between S4-S5. As the specific weights of the solutions decreased, the flow-rates of the pumps increased. The pumps should be used after their flow-rates are determined according to suction head, peristaltic pumps and solutions.

Keywords: Calibration, Hydroponic, Solution, Aging, Specific weight

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Öz

Hidroponik sistemlerde bitkilerin sağlıklı büyümesini sağlamak için peristaltik pompaların çeşitli hidrolik koşullar altında birim zamanda enjekte ettiği besin çözeltisi miktarının belirlenmesi büyük önem taşımaktadır. Bu çalışmanın amacı peristaltik pompaların, emme yüksekliklerinin ve besin çözeltilerinin peristaltik pompanın debisi üzerindeki etkisini test etmektir. Debi testleri eskitme ve ana test olarak gerçekleştirilmiştir. Deneme konuları 3 pompa (PP1, PP2 ve PP3), 2 emme yüksekliği (30 (SH30) ve 60 cm (SH60)) ve 5 çözeltiden (musluk suyu (S1), stok A (S2), stok B (S3), nitrik asit (HNO3) (S4) ve potasyum hidroksit (KOH) (S5)) oluşmuştur. Her iki testte de pompalar tarafından 2 dakika süreyle pompalanan sıvının hacmi belirlenmiş ve akış hızlarının hesaplanmasında hacim-zaman ilişkisinden yararlanılmıştır. Eskitme testleri, eskitme sayısının 2 dakika süreyle 5'e eşit ve büyük olması durumunda yeni peristaltik pompaların besin dozajında kullanılması gerektiğini göstermiştir. Tüm uygulamaların debi üzerinde anlamlı ($p<0.01$) etkisi olmuştur. Pompaların (PP1, PP2 ve PP3) ortalama debileri sırasıyla 102.0, 103.4 ve 103.7 mL dk^{-1} olarak bulunmuştur. PP2 ve PP3'ün debileri PP1'e göre %1.36 ve %1.67 daha fazla olduğu tespit edilmiş ve pompalara göre değişebileceği gösterilmiştir. SH30 ve SH60 için ortalama debileri 103.6 ve 102.5 mL dk^{-1} olarak bulunmuş, emme yüksekliği 30 cm'den 60 cm'ye çıkarıldığında akış hızı %1.1 oranında azalmıştır. En yüksek ortalama akış hızı musluk suyunda (S1=104.7 mL dk^{-1}) elde edilirken, en düşük ortalama akış hızı (S5=101.2 mL dk^{-1}) Stok B'de elde edilmiştir. S1, S2, S4 ve S5 konularının debileri, solüsyonun en düşük debisiyle (S3=101.2 mL dk^{-1}) karşılaştırıldığında sırasıyla %3.51, %1.78, %1.1 ve %2.66 daha yüksek olduğu sonucuna varılmıştır. En yüksek debiler S1-S3 arasında, en düşük debiler ise S4-S5 arasında değişmiştir. Çözeltilerin özgül ağırlıkları azaldıkça pompaların debileri artmıştır. Peristaltik pompalar, emme yüksekliğine ve solüsyonlara göre debileri belirlendikten sonra kullanılmalıdır.

Anahtar Kelimeler: Kalibrasyon, Topraksız tarım, Çözelti, Eskitme, Özgül ağırlık

1. Introduction

In the world the traditional agriculture has experienced problems such as decreased soil fertility, soil degradation caused by continuous cultivation over the years (Cangir and Boyraz, 2008; Kılıç, et al., 2023), and most importantly the decrease in the amount of land per capita, soil-borne diseases and pests, low irrigation efficiency, the increase in the water requirement of cities and industry, and consequently decrease in groundwater. Therefore, there is a need for more productive and ecologically sustainable modern hydroponic farming systems alongside traditional agriculture. Hydroponics are recognized as cultivation systems that provide a reasonable solution to the problems of land and water scarcity, minimizing the risks associated with soil cultivation systems such as soil borne problems (Şimşek and Atila, 2018).

Preparing nutrient solutions, conducting measurements, and monitoring pH and EC levels in hydroponics can be labor-intensive and time-consuming, leading to high costs. The utilization of calibrated injector peristaltic pumps to deliver stock solution, acid, and alkali from their respective containers to the plant nutrient containers offers labor efficiency and enhances the sustainability of hydroponic systems. The use of calibrated peristaltic pumps in hydroponics provides economy in the use of nutrient solutions, increases product quality and yield (Saaid et al., 2013; Chowdhury et al., 2020). Nielsen (1984) suggested that the depleted nutrient and water in the hydroponics should be controlled by automation, considering the water level, nutrient concentration and pH.

In both irrigation and hydroponic systems, various fertilizer dosing systems are available such as fertilizer tanks, hydraulic piston motor injectors, venturi injectors, electric dosing pumps, and hydraulic fertilizer injectors (proportional) (Netafim, 2015). Peristaltic pumps are also commonly used among these systems. Peristaltic pumps find applications in numerous fields such as medicine, agriculture, food processing, chemical analytical equipment, chlorination and dosing, pharmaceutical industry, mining, pulp and paper plants, and more (Way et al., 1990; Klespitz and Kovács, 2014).

The peristaltic pump is a type of positive displacement pump, which is commonly used for transporting a variety of fluids (Jaffrin and Shapiro, 1971; Jacobs et al., 1996; Misra, 2005). The flow is generated in the equipment by periodically pressing a tube segment to the pump housing (the manifold), where the increased pressure will move the fluid, while the backflow is prohibited. The typical configuration of a peristaltic pump commonly consists of a pump segment (which includes tubing), a manifold, and a rotary pump head. The pump head is a rotor, which contains two or more rollers and these rollers exert pressure on the tubing against the manifold; in this way pressure is generated in the tube. Peristaltic pumps can be classified by various properties. One of the most significant differences can be characterized by tubing. In this respect, they can be classified into two groups as the tube and the hose pumps. The most common type of tubing used in peristaltic pumps is made of materials such as silicon, PVC, fluoropolymer, or other polymers. The tube pumps can operate against less pressure, but they need smaller motors and less force to operate. Hence, this way they are space-saving and cheaper. The hose pumps contain a pump segment, which is a reinforced tube, called hose. These hoses are harder to be pressed and therefore they need bigger and stronger motors for the same flow. Hence, they are more expensive to operate. The main advantage of hose pumps is that they can operate against much higher pressure than tube pumps working up to 16 bars (Klespitz and Kovács, 2014).

Since only the interior of the tube of the pump is in contact with the fluid, it is easy to clean the inside surfaces of tube. Furthermore, manufacturing process of the peristaltic pumps are inexpensive, since there are no moving parts in contact with the fluid. Also, the lack of valves, seals and glands makes them comparatively inexpensive to maintain, and the use of a hose or tube makes for a relatively low-cost maintenance item compared to other pump types (Frank's Hospital Workshop, 2023). In addition, mini/small peristatic pumps are made with plastic components because they are lighter and cheaper, also they have to withstand a smaller number of operating hours (Elabbasi et al., 2011). It is important that silicon/plastic tubes in peristaltic pumps are used to prevent corrosion caused by the stock solutions and the entrance of the elements such as aluminum, copper and zinc into the nutrient solution, which could result in toxic levels to the plants (Resh, 2013).

Studies directly aiming the calibration of peristaltic pumps is limited in the literature. However, there are several studies available that are indirectly or directly related to the topic. These studies are summarized as follows. The flow rates of peristaltic pumps were determined as 95 mL min^{-1} by Chowdhury et al. (2020) and 83.33 mL

min^{-1} by Prodoz (2023) since flow rates is very important in dosing systems and but in the studies, the suction + pumping hydraulic head of the peristaltic pump was not specified. In another study, Tandil et al. (2018) calculated the volume of each nutrient according to the plant nutrition receipt and injected the calculated nutrient volumes to the nutrient solution container by controlling 10 peristaltic pumps. Fadillah et al. (2021) mixed the stock solution in A and B containers to the nutrient solution container using the on-off method. Way et al. (1990) tested two peristaltic pumps using undiluted liquid herbicide formulations at two formulation temperatures, and two pump outlet pressures. They found out that the maximum error in the volumetric metering rate was 41% for the smaller pump. Herbicide formulation and temperature significantly affected the mass and volume of herbicide delivered by pump.

The flow rate of peristaltic pumps varies according to the suction+pumping hydraulic head, the concentration/density of the liquid, suction tube diameter, number of revolutions of roller per minute and length of tube (Demir et al., 2020; Frank's Hospital Workshop, 2023). Way et al. (1990) stated that the pumps should be calibrated in application of agricultural chemicals.

It is necessary to know how much nutrient solution a peristaltic pump inject per unit time under different liquid head and concentrations to precise application of water and nutrients in hydroponics. Therefore, aim of this study was to determine the effect of two suction heads and five nutrient solutions on the flow rate of the commercially available three peristaltic pump used in hydroponics. The tests of the flow rate of peristaltic pumps were conducted as aging and main test.

2. Materials and Methods

This study was carried out in laboratory at Kahramanmaraş Sütçü İmam University, Faculty of Agriculture and Department of Biosystem Engineering in 2023. Altitude of working area is about 620 m. Temperature and relative humidity (RH) in the laboratory were measured as between 24-26 °C and 50-55% within the test duration using Hand-Held Thermo Hygrometer. The temperature of the tap water was measured with a thermometer as 21 °C and the temperature of the solutions was measured as 23 °C. In the hydroponic technique, stock A and B nutrient solutions together with acid and alkali regulators are used. In the study, treatments consisted of 3 peristaltic pumps (PP1, PP2 and PP3), 2 different suction heads and 5 different solutions. Three peristaltic pumps (PP1, PP2 and PP3) were selected randomly whether to test there is variations between flow rates of them or not. Suction heads were taken as averages of 30 (SH30) and 60 cm (SH60). The solutions were tap water (S1), stock A (S2), stock B (S3), 0.1 N nitric acid (HNO3) (S4) and 0.1 N potassium hydroxide (KOH) (S5).

In the study, two tests were conducted using 3 peristaltic pumps (PP1, PP2 and PP3). Firstly, to ensure normal operating conditions of the peristaltic pumps, a test called aging test was conducted 10 consecutive times to age the peristaltic pump. Secondly, to determine effect of the parameters on the flow rates of the pumps a test called main test was carried out. Therefore, a workbench was assembled in the laboratory and it consists of bench (1), power supply (2), peristaltic pumps fixing box (3), peristaltic pumps (4), suction and pumping manifold tubes (5), plastic transparent hose (6), a container (7), a cylinder (8) and stand (9). The experiment was performed in the workbench.

1-Bench: Used a bench (width x length x height) of 70 x 120 x 80 cm to set up devices on it.

2-Power supply: Used to regulate 220 volt to 12 VDC and 0.5 A at which peristaltic pump runs.

3- Fixing box of peristaltic pumps: A plastic box (width x length x height) of 25 x 25 x 25 cm on which three peristaltic pumps were fixed.

4-Peristaltic pumps: Mini pump with model of NKP-DC-S10B, color blue, operating voltage of 12 DC, power of 5 watt, head configuration with peristaltic (3 rolling wheel), pump tube material with silicone, style with submersible, medium with liquid, maximum flow rate ≥80 ml/min, working temperature and humidity of 0-40°C and <%80 (Kamoer, 2023a).

5-Silicon tube: Used as manifold tube (S10) being 3 mm inside and 5 mm outside diameter and 5 cm long.

6-Plastic transparent hose: Used in the tests as suction and pumping hose being 4 mm inside and 6 mm outside diameter, and 30 and 60 long cm.

7-Container: Used plastic a container of 6 L volume for solutions to be pumped. Sizes of the container (width x length x height) were of 10 x 15 x 40 cm.

8-Cylinder: Used a gradated glass cylinder of 250 mL volume to measure solutions pumped.

9-Stands: Used stand (width x length x height) of 25 x 25 x 30 cm for SH30.

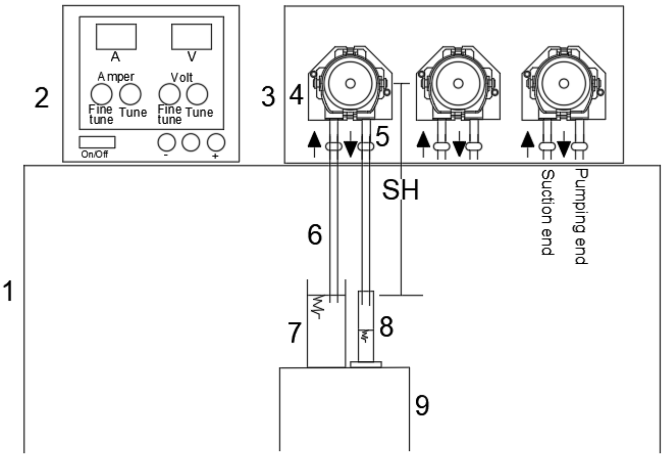

Figure 1. The experimental bench to determine the flow rates of peristaltic pumps

Before each test of new and have not been used peristaltic pumps (PP1, PP2 and PP3), their positive (12 VDC) and zero (0) poles were separately wired to (12 VDC) and zero (0) poles of power supply. Before starting each test, volt and ampere of power supply were tuned to 12 VDC and 0.5 A, respectively.

Chemical content of tap water used in the preparation of nutrient solutions and aging test was given in *Table 1*. Since electrical conductivity of tap water is low, its contribution to property of the nutrient solution become low (Kanber and Ünlü, 2010).

Table 1. Chemical content of tap water used in the aging test and in the preparation of nutrient solutions

EC mS/m	pH	Cations (ppm)			Anions (ppm)			
		$(Ca^{+2})+(Mg^{+2})$	Na^{+1}	K^{+1}	CO_3^{-2}	HCO_3^{-1}	SO_4^{-2}	Cl^{-1}
0.410	7.26	7.6	0.02	0.07	-	2.00	0.58	1.60

In the calculation of concentrations of reagents, a software called HydroBuddy developed by Pinto (2022) was used. The program calculates nutrient solutions for hydroponics and general agriculture. HydroBuddy has many features and some of them were given below:

-Calculates the weights of specific substances needed to arrive at specified concentrations of different elements (formulation to salt weights calculation)

-Contains library with commonly available fertilizer salts

-Includes ability to save and load lists of substances used for calculations.

-Empirical model for the prediction of EC

-Calculations in ppm, mmol/L, mol/L and meq/L.

-Calculations for both direct additions and A+B concentrated solutions

-Use any custom substance as a part of an A+B concentrated solution calculation

To calculate concentrations of reagents used in the preparation of Stock A and B nutrient inputs of HydroBuddy were given following.

In the main page of program, low limits of optimal concentration ranges of major elements and micronutrients by Jones (2005), and reagents by Jones (2014) in *Table 2* were inputted as target concentration (ppm) and substance selection, respectively. Solution volume was enter as 5 and unit was selected as liters, concentration unit as ppm, mass unit as gram and solution preparation type as concentrated A+B solutions.

In preparations of Stock A and B nutrient solution, the firstly determined weights of reagents were putted separately A and B containers with 6 L and then tap water was completed the two containers up to 5 L level and then mixed.

To prepare solutions of 0.1 N nitric acid (HNO_3) (Niu and Masabni, 2022) and 0.1 N potassium hydroxide (KOH) (Triantino et al., 2022) for 1 L, required weights of nitric acid (HNO_3) and potassium hydroxide (KOH) were calculated manually. Solutions of 0.1 N nitric acid (HNO3) and 0.1 N potassium hydroxide (KOH) of 1 L was prepared following method of preparation of Stock A and B nutrient solution. The calculated concentrations of the reagents, acid and alkali substances and EC of the final nutrient stock solutions by HydroBuddy were given in *Table 3.*

Table 2. Major Element and Micronutrient Ionic Forms and Normal Concentration Range Found in Most Nutrient Solutions (Jones, 2005)

Elements	Ionic Form	Concentration (mg/L, ppm)
Macro elements		
Nitrogen (N)	NO_3, NH_4	100-200
Phosphorus (P)	HPO_4 , H_2PO_4	15-30
Potassium (K)	K^+	100-200
Calcium (Ca)	Ca^{+2}	200-300
Magnesium (Mg)	Mg^{+2}	30-80
Sulfur (S)	SO_4^{-2}	70-150
Microelements		
Boron (B)	BO_3^{-3}	0.03
Copper (Cu)	Cu^{+2}	0.01-0.10
Iron (Fe)	Fe^{+2}, Fe^{+3}	2-12
Manganese (Mn)	Mn^{+2}	0.5-2.0
Molybdenum (Mo)	MoO_4^{-1}	0.05
Zinc (Zn)	Zn^{+2}	0.05-0.50

Table 3. Reagents and their calculated weights used in preparation of stock A and B nutrient for volume of 5 liters, and acid and alkali solutions for volume of 1 liters (Jones, 2014).

Reagents	Formula	Mass (g for 5 L)
Stock A		
Iron EDTA	Fe (EDTA)	7.692
Calcium Nitrate (Tetrahydrate)	$Ca(NO_3)_2$•$4H_2O$	511.472
Potassium nitrate	KNO_3	59.406
Stock B		
Ammonium Orthamolybdate	$(NH_4)_2MoO_4$•	0.051
Boric Acid	H_3BO_3	0.086
Copper Sulfate (Pentahydrate)	$CuSO_4$•$5H_2O$	0.098
Magnesium Sulfate (Heptahydrate)	$MgSO_4$•$7H_2O$	152.13
Manganese sulfate (Monohydrate)	$MnSO_4$ H_2O	0.769
Potassium Monobasic Phosphate	KH_2PO_4	70.508
Zinc Sulfate (Dihydrate)	$ZnSO_4$•$2H_2O$	0.076
Acid		
Nitric acid	HNO_3	6.3 (for 1 L)
Alkali		
Potassium hydroxide	KOH	4 (for 1 L)

Since the chemical contents of the solutions are different, the specific weights of solutions (S1, S2, S3, S4 and S5) will also be different. In this context, the specific weights of the solutions were determined from Equation 1 (Mutaf, 2004; Doğan, 2008).

$$\rho = \frac{M}{V} \quad \text{(Eq. 1)}$$

Where; ρ; specific weight of solution (mL/g), M; mass of solution (g), V; is the volume of the solution (mL). While measuring the volume of the solutions, the temperature of each solution was also measured with a thermometer.

The suction head (SH) was considered as the water head between the top of water in the container and the center of the peristaltic pump. Since the head of discharge of peristaltic pomp is below the peristaltic pump center, it is taken as zero. As suction head increase, energy use of pumps and hose cost increase (Salmasi et al., 2022). Chowdhury et al. (2020) selected suction head as between 20-60 cm in their study. That is why in this study, suction heads in the SH30 and SH60 treatments were selected as 30 and 60 cm.

Before testing the flow rate of peristaltic pumps (PP1, PP2 and PP3), which are the new and have not been used before (called main test), to ensure their normal operating conditions 10 consecutive aging tests were carried out in the workbench using tap water (S1) at the SH30 treatment. On the other hand, main tests were conducted at the both SH30 and SH60 treatments. Duration of aging test and main test was 2 minutes. For aging test and main test of three peristaltic pumps, same manifold silicone tubes with 3 mm inside and 5 mm outside diameter and 5 cm long were used. Both the stand of 25 x 25 x 30 cm size and nutrient solution depth of 32.5 cm in the container were used to constitute 30 cm suction head of peristaltic pumps at the aging and main tests (*Figure 2a*). Accordingly, plastic transparent hose of 30 cm was attached to the suction and pumping end of the manifold using nipple. The suction head of 60 cm at SH60 treatment in main test was constituted as given in figure 2b. Plastic transparent hoses of 60 cm were attached end of manifold suction and pumping using nipple. Depth of that's in the SH60 main tests was same that's of SH30 and but no stand was used (*Figure 2b*).

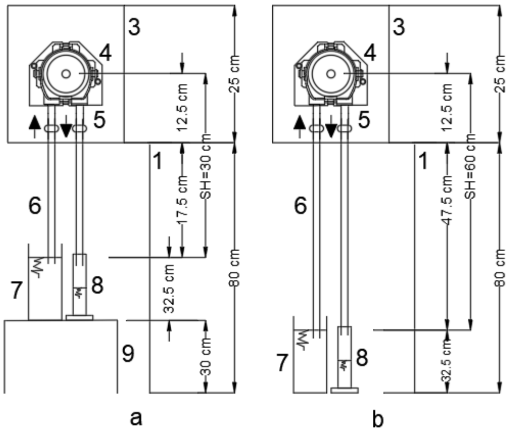

Figure 2. Arrangement of suction head of peristaltic pump for SH30 and SH60 treatments

The experiment was carried out in complete factorial design with 3 replications (3 peristaltic pumps x 2 suction heads x 5 fluid x 3 repetitions).

In both the aging and main tests to calculate flow rates of the peristaltic pumps, the volume-time relationship were utilized (Chowdhury et al., 2020). In all tests of treatments, the volume of liquid pumped by the peristaltic pumps for 2 minutes was determined. During this time period, the volumes pumped by the peristaltic pumps were measured with a graduated measuring cylinder. Flow rate of peristaltic pumps is determined by Equation 2.

$$Q = \frac{V}{t} \quad \text{(Eq. 2)}$$

Where; Q; flow rate of peristaltic pumps (mL min^{-1}), V; volume of solution pumped by the peristaltic pump (mL), t; is the operating time (minutes) of peristaltic pumps.

Flow rates of the treatments were evaluated using ANOVA and Duncan (except suction head) test in SPSS.

3. Results and Discussion

To ensure the healthy growth of plants in hydroponics, it is crucial to determine the amount of nutrient solution that peristaltic pumps inject per unit time under various hydraulic conditions. So, the tests were conducted to determine the effect of three peristaltic pumps, 2 suction heads and five nutrient solutions on the flow rate of the peristaltic pump in the laboratory.

The specific weights of the solutions (S1, S2, S3, S4 and S5) were calculated as ρ_1=0.97, ρ_2=1.13, ρ_3=1.19, ρ_4=0.97 and ρ_5=1.00 g mL^{-1} (*Figure 3*). The highest specific weight was found for stock B (ρ_3=1.13 g mL^{-1}) and the lowest one was found for tap water (ρ_1=0.97 g mL^{-1}). The specific weights of the solutions varied according to the chemical contents of nutrient solutions.

In the aging test, results of ten successive flow rate of the new and have been unused peristaltic pumps were given in *Figure 4*. As seen in *Figure 4*, in the first two aging tests, the flow rate of the peristaltic pumps was low, about 95-100 mL min^{-1}, and then it increased until the 5th aging tests. After that, the flow rates began to approach stable values, and on the 10th aging tests, they reached to about stable value of 105-105.5 mL min^{-1}. These results showed that the new peristaltic pumps should be used in nutrition dosing after aging 5-10 times (10-20 minutes). Kamoer (2023b) stated that new peristaltic pumps should be used after they were aged for 30 minutes.

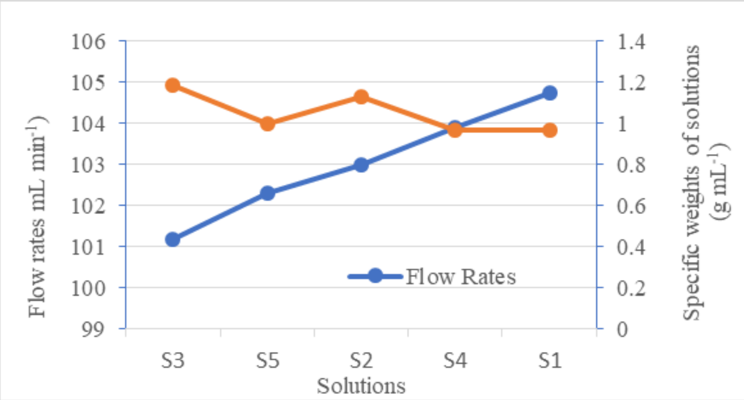

Figure 3. Variation of flow rates and specific weights according to solutions

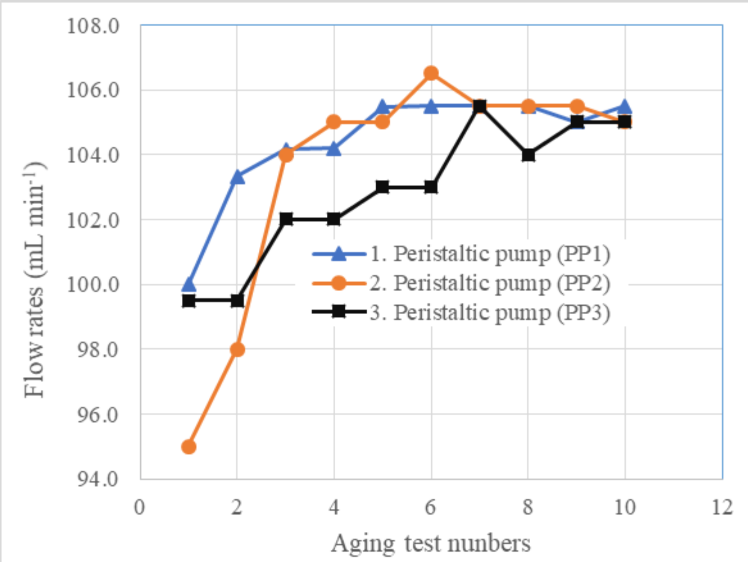

Figure 4. Flow rates of peristaltic pumps according to the aged test numbers.

The mean flow rates of the peristaltic pumps (PP1, PP2 and PP3) were found to be 102.0, 103.4 and 103.7 mL min^{-1}, respectively. At the SH30 and SH60, their mean flow rates were 103.59 and 102.5 mL min^{-1}. The lowest average flow rate (95.5 mL min^{-1}) was determined for SH60S3PP2, and the highest average flow rate (107.3 mL min^{-1}) was determined for SH30S4PP3. Others varied between these two flow rates (*Table 4*).

ANOVA test was performed and effects of peristaltic pump, different suction heads and solutions on flow rates of the peristaltic pumps were found to be statistically significant ($p<0.01$). In addition, groups of flow rates of parameters except suction head were determined by Duncan test. Flow rates of peristaltic pumps are statistically classified into 2 groups. PP2 and PP3 formed the first group and PP1 formed the second group (*Table 5*). The flow rates of PP2 and PP3 are 1.36% and 1.67% greater than that's of PP1, respectively. Although the tube peristaltic pumps are manufactured in the same way, their flow rates could vary. These results show that flow rates could vary with the peristaltic pumps (Way et al., 1990).

The effect of SH30 and SH60 on flow rates was statistically significant ($p<0.01$). It was grouped according to ANOVA not Duncan. Accordingly, SH30 was in the first group because it had a higher flow rate (103.59 mL min^{-1}), and SH60 with a low flow rate (102.46 mL min^{-1}) was in the second group (*Table 5*). This result shows that the peristaltic pump flow rate decreases by 1.1% when the suction head increases from 30 cm to 60 cm.

Table 4. Flow rates calculated from the treatments

Suction Heads (cm)	Nutrient Solutions	Flow rates of peristaltic pumps (mL min^{-1})		
		PP1	**PP2**	**PP3**
SH30	S1	104.5	105.5	104.7
	S2	102.2	104.3	99.7
	S3	101.0	104.5	103.3
	S4	101.3	106.2	107.3
	S5	102.0	102.7	104.7
SH60	S1	104.6	105.3	103.8
	S2	103.3	104.8	103.7
	S3	99.7	95.5	103.2
	S4	101.0	102.5	105.0
	S5	100.3	102.5	101.7

The effects of the five solutions on the flow rates were found to be statistically different ($p<0.01$) and classified into 5 group (*Table 5*). The average flow rates of S1, S2, S3, S4 and S5 were calculated as 104.7, 103.0, 101.2, 103.9 and 102.3 mL min^{-1}. The mean flow rates of the solutions are ordered from the highest to lowest, as S1 (104.74 mL min^{-1}), S4 (103.89 mL min^{-1}), S2 (103.00 mL min^{-1}), S5 (102.31 mL min^{-1}), and S3 (101.19 mL min^{-1}). The highest average flow rate was obtained in tap water (S1=104.7 mL min^{-1}) with the lowest specific weight (ρ_1=0.97 g mL^{-1}), while the lowest average flow rate (S5=101.2 mL min^{-1}) was found for Stock B with highest specific weight (ρ_3=1.19 g mL^{-1}). Flow rate of the S1, S2, S4 and S5 compared with the lowest flow rate of solution (S3=101.2 mL min^{-1}) were found to be higher as 3.51%, 1.78%, 1.1% and 2.66%, respectively. The largest flow rate change was between S1-S3, and the lowest between S2-S5 (*Table 4*). The specific weights of the nutrient solutions inversely affected the flow rate (Gebhardt et al., 1984). As the specific weights of the solutions decreased, the flow rates of the peristaltic pumps increased. Nutrient solutions with different specific weight have been used in hydroponic (Jones, 2005) and it is crucial to determine the amount of nutrient solution that peristaltic pumps inject per unit time under various hydraulic conditions. For this reason, calibration of the peristaltic pumps (determining their flow rates) is very important for the healthy development of hydroponic plants (Chowdhury et al., 2020). Way et al. (1990) reported that peristaltic pumps should be calibrated in the application of agrochemicals.

Table 5. Classification of flow rates determined according to peristaltic pumps, suction heads (except) and nutrient solutions by Duncan test

Peristaltic Pumps		Suction Heads		Nutrient Solutions	
PP3	$103.70^{a} \pm 0.32$	SH30	103.59 ± 0.32	S1	$104.74^{a} \pm 0.21$
PP2	$103.38^{a} \pm 0.55$	SH60	102.46 ± 0.39	S4	$103.89^{b} \pm 0.69$
PP1	$101.99^{b} \pm 0.38$			S2	$103.00^{c} \pm 0.46$
				S5	$102.31^{d} \pm 0.35$
				S3	$101.19^{e} \pm 0.74$

The relationship between the specific weights of the solutions and the flow rates is given in *Figure 4*. As can be seen from the figure, as the specific weight of the solution decreased, the flow rate of the peristaltic pumps increased (Demir et al., 2020). The results show that the specific weight of the solution has a significant effect on the flow rate of the peristaltic pump. Chowdhury et al. (2020) determined the flow rate of the peristaltic pump as 95 mL min^{-1}. and Prodoz (2023) states that its flow rate is 83.33 mL min^{-1}. However, these researchers did not give any information about the suction head of the peristaltic pump and the chemical content of the solution while testing the flow rate of the peristaltic pump. The flow rate of the peristaltic pump given by Chowdhury et al. (2020) and Prodoz (2023) are lower than the average peristaltic pump flow rate determined in this study.

In conclusion, pump-specific flow rates should be determined by taking into account the suction head, the peristaltic pump and the chemical contents of the solution. The pump-specific flow rates should be used in dosing of nutrient solution (fertilizer), acid and alkali in hydroponic automation systems.

4. Conclusions

In the study, the new peristaltic pumps should be used in nutrition dosing after 10-20 minutes of run. The effect of 3 peristaltic pumps, 2 suction heads and 5 nutrient solutions on the flow rate was determined to be statistically different. This means that peristaltic pumps, suction heads and nutrient solutions affect flow rate of the peristaltic pumps. For this reason, pump-specific flow rates must be determined taking into account the suction head, the peristaltic pump and the chemical contents of the solution. The pump-specific flow rates should be used dosing of nutrient solution (fertilizer), acid and alkali in hydroponic automation systems.

Ethical Statement

There is no need to obtain permission from the ethics committee for this study

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: GENÇOĞLAN, C., GENÇOĞLAN, S.; Design: GENÇOĞLAN, C., GENÇOĞLAN, S.; Data Collection or Processing: GENÇOĞLAN, C., GENÇOĞLAN, S.; Statistical Analyses: GENÇOĞLAN, C., GENÇOĞLAN, S.; Literature Search: GENÇOĞLAN, C., GENÇOĞLAN, S.; Writing, Review and Editing: GENÇOĞLAN, C., GENÇOĞLAN, S

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