Determination of mechanical force generated by growing seed in inkjet 3D printed microdevice

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Abstract. An inkjet 3D printed microdevice for germinating seed root and stalk driving force measurement is proposed. The device consists of two cantilever-type sensors for the forces monitoring. The cantilevers are first mechanically characterized by force-deflection measurements. Deflection of the cantilevers in the microdevice is determined by optical analysis of the captured “micropot” images. Then deflection is converted to force value. Successful monitoring of the root and stalk driving forces in different cultivation mediums was achieved.

1. Introduction
Generation and potential application of microscale actuation force of growing seed is a new research area. The generated force is an information about biological potential of the seed but also can be applied as a source of microscale energy that can be converted from mechanical to electrical energy. Knowledge on value and dynamics of generated force is a first step towards development of the micro-bio-mechano-electrical converter. On the other side novel microengineering techniques like 3D printing opens new ways and possibilities in development of miniaturized devices. In our previous works we demonstrated that inkjet 3D printing is a powerful tool in development of microfluidic devices, check microvalve or miniature water turbine energy harvester [1-6]. 3D printing enables almost non limited geometry of the printouts with dimensions down to submillimeter scale. However, some properties of the miniature printouts like mechanical behavior of the microengineered elements are unknown and hard to model. In this paper we present an inkjet 3D printed microdevice for determination of growing seed actuation force. The microdevice enables determination of potential of the growing seed by measurement of the driving force of root and stalk. The device consists of two cantilever-type sensors for the forces monitoring. The cantilevers are first mechanically characterized by force-deflection measurements. Deflection of the cantilevers is determined by optical analysis of the captured microdevice images and then deflection is converted to force value. Successful monitoring of the mechanical force generated by the root and stalk in different cultivation mediums was obtained.

2. Inkjet 3D printed microdevice

2.1. The microfluidic device with integrated force sensors
A fully 3D printed microdevice with integrated cantilever-type force sensors with optical method of root and stalk force measurements was developed. Our solution is modular one with integrated
microcantilevers and a microfluidic channel for continuous supplying of a growing medium (including optional on-chip flow measurement by Venturi effect flowmeter. The microdevice is fabricated by Projet 3510 printer (3D Systems, USA), Visijet M3 Crystal is used as a building material and S300 as support material. The 3D printed cantilever-type force sensors are 4 mm long and 2 mm wide (fig. 1). The microdevice is disposable with easy seed positioning and fluidic connections.

Figure 1. The microdevice (micropot – µpot) for growing seed root and stalk driving force determination – computer visualization with marked the main components (left image) and the 3D printed device (right image).

2.2. Mechanical properties of 3D printed cantilevers
The 3D printed cantilever-type force sensors were 4 mm long, 2 mm wide and from 200 μm to 600 μm thick. The cantilevers were printed in two orientations in relation to printing head movement (Fig. 2). As it was already demonstrated by us [3], printing direction – parallel (PP) or perpendicular (PR) – influence mechanical properties of the printed micromechanic elements. The cantilevers were mechanically characterized by Bondtester Dage 4000 Plus (Nordson Dage, Germany). Due to technical limitations, mechanical characterisation was stopped when the force or deflection reached 600 mN or 1300 μm. Deflection versus force characteristics were collected for several samples for both printing orientations (Fig. 3). The characteristics are linear and it is possible to fit them with linear function that is applied later in the software for displacement-force determination.

Figure 2. Printing orientation (red arrow) of the cantilevers – parallel (PP) and perpendicular (PR)

Figure 3. Displacement versus force for different thicknesses of the cantilevers and printed in PP (left characteristics) and PR (right characteristics).
The cantilevers bend in a wide range (more than 1 mm) but strong dependence on cantilever thickness and printing orientation was observed (Fig. 4).

Figure 4. Image of the bended cantilever (4 mm long and 200 μm thick) and force to deflection ratio for different cantilever lengths and thicknesses.

2.3. Measurement set-up

Root/stalk driving force measurement system (Fig. 5) is based on the image processing of the deflected cantilevers. Images are recorded by a camera and analyzed by dedicated home-made software. Microcantilevers mechanical parameters are implemented to this software to determine the driving force depending on sensor deflection. The images are captured with 1 hour period. *Lepidium sativum* seeds were investigated as a model plant. During the seed growth the microdevice were supplied with tap water or nutrient (BIOHUMUS, natural nutrient, EKODARPOL) using piezoelectric mp6-series micropumps (Bartels, USA) through 500 μm microchannel with 2 ml/h flow at 22°C temperature under halogen lamp illumination.

Figure 5. Block scheme of the measurement system for root/stalk driving force determination.

3. Results

We successfully collected the images of bended cantilevers during root and stalk growth (Fig. 6). It was obtained for 200 μm thick cantilever coupled with the root and 400 μm thick for the stalk (both 4 mm long). Modular construction of the device enables adjustment of the cantilever thicknesses for various force ranges and seeds. The maximum measured driving force was equal to 0.095 N for the root and 0.9 N for the stalk for the seed supplied with tap water (Fig. 7). It was noticed that stalk exhibits significantly higher driving force (around 1 N) than the root. Both forces increased almost linearly as growing time function. Influence on the growing potential in the presence of the nutrients was measured and it was clearly visible that the time of stalk and root development was reduced and the growing force was
increased. The stalk driving force reached 1.7 N (almost two times higher value in comparison to growth without nutrient).

Figure 7. Driving forces determined for growing *Lepidium sativum* as function of time for root (upper characteristic) and stalk (lower characteristic).

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