Physical Properties of Biocontainers Used to Grow Long-term Greenhouse Crops in an Ebb-and-flood Irrigation System

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Abstract. The physical properties of new 15.2-cm plastic and comparably sized bioplastic, solid ricehull, slotted ricehull, paper, peat, dairy manure, wood fiber, rice straw, and coconut fiber containers were determined. Additionally, the physical properties of these containers were determined after being used to grow ‘Rainier Purple’ cyclamen (*Cyclamen persicum* L.) in ebb-and-flood benches for 15 weeks in a greenhouse environment. The punch strength of new coconut fiber containers was the highest of the containers. The used plastic containers had strengths of 228.0, 230.5, and 215.2 N for the bottom, middle, and top zones, respectively. The used peat, dairy manure, and wood fiber containers had strengths of less than 15 N for each zone. Tensile strength of all new containers was 10 kg. The plastic, bioplastic, solid ricehull, slotted ricehull, paper, and coconut fiber containers had used strengths that were similar to plastic containers. Total water used for wood fiber containers was higher than plastic containers. Irrigation intervals for plastic containers were similar to bioplastic, solid ricehull, slotted ricehull, paper, and coconut fiber containers. The irrigation interval for plastic containers was 1.32 days and the wood fiber container had the shortest irrigation interval at 0.61 day. Container absorption for coconut fiber containers was 255 mL and was higher than plastic containers. Wood fiber container absorption was 141 mL and lower than plastic containers. Plastic, bioplastic, solid ricehull, and slotted ricehull containers had no visible algal or fungal growth. The wood fiber containers had 79% of the container walls covered with algae or fungi and the bottom and middle zones had 100% algae or fungi coverage. The bottom zone of rice straw, dairy manure, and peat containers also had 100% algae or fungi coverage. The bioplastic, solid ricehull, and slotted ricehull containers in this study proved to be good substitutes for plastic containers. These containers retained high levels of punch and tensile strength, had no algal and fungal growth, and required a similar amount of solution as the plastic containers to grow a cyclamen crop. The peat, dairy manure, wood fiber, and rice straw containers proved not to be appropriate substitutes for plastic containers because of the low used strengths, high percentage of algal and fungal coverage, and shorter irrigation intervals as compared with plastic containers.

The greenhouse floriculture crop production industry compromises such commodities as flowering potted crops, perennials, and annual bedding plants. This sector of the horticulture production industry was valued at \$3.83 billion for the top 15 producing states in 2009 (USDA, 2010). Most greenhouse floriculture crops are grown in containers. The container size is dictated by the length of time the crop will be in production and the desired finished plant size. For example, florist potted crops such as poinsettia

(*Euphorbia pulcherrima* L.) and chrysanthemum (*Chrysanthemum* × *morifolium* Ramat) require longer production times to grow and are typically grown in larger containers than annual bedding plants.

Petroleum-based plastics (plastic) are the most common materials used to fabricate containers for greenhouse crop production. Plastic is relatively strong, resists mildew and algae growth, and can be molded into a variety of shapes and sizes. However, after use, these containers are typically discarded, and this results in large amounts of waste plastic containers going to landfills. One potential solution to the large amounts of waste plastic greenhouse containers is the use of biocontainers. Biocontainers are generally defined as containers that are not petroleum-based and break down quickly when planted into the soil or placed into a compost pile.

Biocontainers are generally categorized as being plantable or compostable (Evans and Hensley, 2004; Evans et al., 2010). Plantable

biocontainers are containers that allow plant roots to grow through their walls and may be directly planted into the final container, the field, or the planting bed. Compostable biocontainers cannot be planted into the soil because the roots cannot physically break through the container walls, and the biocontainers do not break down quickly enough to allow the plant roots to grow through the container walls. Instead, these containers must be removed before planting but can be placed in a compost pile to decompose in a relatively short time (Mooney, 2009).

There are many types of plantable biocontainers and some of them are described here. Composted dairy manure containers (CowPot Co., Brodheadsville, PA) are made of composted, compressed cow manure held together with a binding agent. Peat containers (Jiffy Products, Kristiansand, Norway) are made from peat and paper fiber. Paper containers (Western Pulp Products, Corvallis, OR, and Kord Products, Lugoff, SC) are made from paper pulp with a binder. Rice straw containers (Ivy Acres, Inc., Baiting Hollow, NY) are composed of 80% rice straw, 20% coconut fiber, and a proprietary natural adhesive as a binder. Wood fiber containers are composed of 80% cedar fibers, 20% peat, and lime (Fertil International, Boulogne Billancourt, France). Coconut fiber containers are made from the medium and long fibers extracted from coconut husks and a binding agent (ITML Horticultural Products, Brantford, Ontario, Canada). One type of compostable biocontainer available for greenhouse production is the ricehull container, which is made of ground rice hulls with a binding agent (Summit Plastic Co., Tallmadge, OH). These containers are available in different sizes and may have solid or slotted walls. Another group of compostable biocontainers are bioplastic containers, which are made from a bioplastic derived from polylactic acid or wheat starch that is then thermoformed into containers (OP47; Summit Plastic Co.).

Most research on biocontainers for greenhouse crops production has focused on water use, algae growth on the container walls, strength of the containers, and plant growth in the containers. Evans and Karcher (2004) found that when comparing peat, feather fiber, and plastic containers, the peat containers had the highest rate of water loss through the container walls, and both feather fiber and peat containers required more water and more frequent irrigations when growing a crop than the traditional plastic containers. When various biocontainers and plastic containers were compared, the crops grown in peat and wood fiber containers had the highest water use (Evans et al., 2010), but the frequency of irrigation and amount of water used were not significantly different among bioplastic, ricehull, and traditional plastic containers.

The percent of the biocontainer surface covered by algae or fungi has been another area of interest to researchers because algal or fungal growth was considered unattractive and could affect marketability. Evans and Hensley (2004) reported that feather fiber containers

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had 5.3% of their surface covered with algal and fungal growth and peat containers had 56% of their surface covered. In a similar study, Evans et al. (2010) found that 48% of the surface of the peat container was covered with algae after 8 weeks in a greenhouse. The bioplastic, coconut fiber, ricehull, and plastic containers had no algal or fungal growth on the container walls.

Container dry and wet strengths have been considered important because the containers need to be strong enough for handling, packaging, and shipping, and therefore, container strength has been extensively evaluated. Evans et al. (2010) measured the dry vertical and lateral strengths of traditional plastic and eight biocontainers and found the dry vertical strength of ricehull containers was 70 kg giving it the highest dry vertical strength of all containers tested. The containers with the lowest dry vertical strength were the bioplastic and rice straw containers. The paper and ricehull containers had the highest dry lateral strengths at 60 and 50 kg, respectively. The remaining biocontainers had dry lateral strengths of less than 20 kg. Evans and Karcher (2004) demonstrated that peat containers had higher dry longitudinal breaking strength than plastic or feather fiber containers. Evans et al. (2010) compared wet vertical strengths of various biocontainers. They found that plastic containers had a wet vertical strength of 55 kg and wet lateral strength of 20 kg. Ricehull and paper containers had wet vertical strengths of 45 and 55 kg, respectively. Ricehull containers also had the highest wet lateral strength of all the containers at 55 kg. The bioplastic, wood fiber, dairy manure, coconut fiber, peat, and rice straw containers all had wet lateral and vertical strengths of less than 10 kg. In another study, Evans and Karcher (2004) reported that the wet longitudinal and lateral strengths of plastic containers were higher than those of peat and feather containers.

Most of the research conducted on the physical properties of biocontainers has been focused on short-term crops such as annual bedding plants grown using overhead irrigation systems. However, many greenhouse crops are grown as potted florist crops that require longer production times than bedding plants and are often grown in larger containers using subirrigation systems such as ebb-and-flood benches or flood floors. Therefore, the objective of this research was to evaluate the physical properties of biodegradable containers compared with plastic containers for the production of long-term crops using a subirrigation system.

Materials and Methods

The containers evaluated included: 15.2-cm injection-molded polypropylene plastic (Dillen Products, Middlefield, OH), 15.2-cm solid ricehull (Summit Plastics Co.), 15.2-cm slotted ricehull (Summit Plastics Co.), 12.5-cm bioplastic (Summit Plastics Co.), 15-cm coconut fiber (ITML Horticultural Products), 14.5-cm rice straw (Ivey Acres), 12.7-cm peat (Jiffy

Products), 14-cm wood fiber (Fertil International), 15.5-cm paper (Western Pulp Products), and 15-cm composted dairy manure containers (CowPot Co.). The dimensions of the containers tested are shown in Table 1. The

15.2-cm plastic container served as the control for all biocontainers.

Eight-leaf plugs (number 50 plug trays with volume of 30.8 mL; Wagner Greenhouses, Minneapolis, MN) of 'Rainier Purple'

Table 1. Heights, diameters, and volumes of plastic and various biocontainers used.

Container	Ht (cm)	Top diam (cm)	Bottom diam (cm)	Volume (mL)	Classification
Plastic	14.5	15.2	10.3	1840	—
Bioplastic	9.5	12.5	9.5	840	Compostable
Solid ricehull	11.0	15.2	11.0	1240	Compostable
Slotted ricehull	11.0	15.2	11.0	1240	Compostable
Paper	17.0	15.8	12.0	2350	Plantable
Peat	9.5	12.7	9.0	630	Plantable
Dairy manure	12.0	15.2	10.7	750	Plantable
Wood fiber	14.0	14.0	11.0	1700	Plantable
Rice straw	17.0	14.5	10.0	1500	Plantable
Coconut fiber	9.5	15.0	10.8	1270	Plantable

Fig. 1. Punch strength by zone of new 15.2-cm plastic containers and various biocontainers. Lower zone for all containers was 0 to 2 cm high. Middle and upper zones were determined by taking the remaining height of the container and dividing it in half creating two zones of equal height. NS, *, **, *** Nonsignificant or significantly different from the plastic control at $P > F = 0.05, 0.01, \text{ or } 0.001$, respectively.

Fig. 2. Punch strength by zone of 15.2-cm plastic containers and various biocontainers after being used to grow 'Rainier Purple' cyclamen for 15 weeks in an ebb-and-flood system. The bottom zone for all containers was 0 to 2 cm from the bottom of the container and middle and upper zones were determined by taking the remaining height of the container wall and dividing it in half creating two zones of equal height. Bars noted with *** are significantly different from the plastic control at $P > F = 0.001$.

cyclamen (*Cyclamen persicum* L.) were transplanted into the containers described previously filled to the container rim with a 75:25 peat:perlite root substrate (Sun Gro Horticulture, Bellevue, WA). Cyclamen was chosen for this study because it was a long-term greenhouse crop and a day-neutral plant. All containers were placed in a glass-glazed greenhouse in Fayetteville, AR, on 1 m × 1 m × 15-cm ebb-and-flood benches. Greenhouse air temperatures ranged from 18 to 32 °C and light levels ranged from 350 to 440 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at 1200 HR during the experimental periods. The experiment was conducted Feb. to June 2010, Sept. 2010 to Jan. 2011, and Feb. to June 2011. For each block, one type of container was randomly assigned to a bench.

All containers were irrigated by flooding benches to a depth of 2 cm for 10 min with a solution containing 100 $\text{mg}\cdot\text{L}^{-1}$ nitrogen using a 15N-4.3P-20.8K water-soluble fertilizer (Peters Professional 15-10-25 Poinsettia Peat-Lite; Scotts, Marysville, OH). Each bench contained nine of a single type of container. Benches were irrigated individually when the moisture level of three of the containers within a bench decreased below 40% (v/v) using a Waterscout SM100 Moisture Sensor on the soilless setting at 21 °C (Spectrum Technologies, Plainfield, IL). The moisture level of each container was checked four times per day.

Each ebb-and-flood bench stock tank was filled with fertilizer solution (solution) to 100 L before each irrigation and the amount of solution needed to refill the stock tank to 100 L after irrigation and drainage was recorded. After 15 weeks, the experiment was ended and the total water used per container to grow a crop was calculated by summing all the water used for a bench at each irrigation and dividing by nine to obtain the average water used per container over the production period. The average irrigation interval and average container solution uptake per irrigation were also determined.

At the completion of the study, the substrate was removed and container strength was tested. To maintain consistency across blocks, the containers were irrigated and strength was tested 4 h later. Each container was divided into three zones by height. The bottom zone for all containers was the lowest 2 cm of the container. The middle and upper zones were determined by taking the remaining height of the container wall and dividing it in half creating two zones of equal height (plastic: bottom zone: 0–2 cm, middle zone: 2–8.25 cm, top zone: 8.25–14.5 cm; solid ricehull and slotted ricehull: bottom zone: 0–2 cm, middle zone: 2–6.5 cm, top zone: 6.5–11 cm; bioplastic, coconut fiber, and peat: bottom zone: 0–2 cm, middle zone: 2–5.75 cm, top zone: 5.75–9.5 cm; rice straw and paper: bottom zone: 0–2 cm, middle zone: 2–9.5 cm, top zone: 9.5–17 cm; wood fiber: bottom zone: 0–2 cm, middle zone: 2–8 cm, top zone: 8–14 cm; and dairy manure: bottom zone: 0–2 cm, middle zone: 2–7 cm, top zone: 7–12 cm) and each zone was tested for punch

strength individually. Punch strength was tested by measuring the amount of force required to punch through the container wall with a 5-mm ball probe at a crosshead speed of 10 mm per second using a texture analyzer machine (TAXT 2I; Texture Technologies, Scarsdale, NY). This procedure was also used to test new containers.

Tensile strength of new or used containers was tested by suspending the containers 12 cm above a catch basin. The containers were leveled and increasing amounts of weight using 4.5-mm diameter steel balls (354 mg each) were added until the container walls separated or the container bottoms broke. The maximum test weight for this test was 10 kg.

For determination of the percentage of container outer walls covered with algae or fungi, containers were air-dried and individual containers were divided into three zones by container height as previously described. The total container surface area and zone surface area discolored with fungal or algal growth were determined using a LI-COR Li-300 area meter (LI-COR, Lincoln, NE). The discolored surface area was expressed as a percentage of the total surface area and as a percentage of the surface area of the zone.

The experimental design was a complete randomized block design with an ebb-and-flood bench serving as an experimental unit. The experiment was repeated three times. An

Fig. 3. Tensile strength of new and wet used 15.2-cm plastic containers and various types of biocontainers. Used containers were tested after growing 'Rainier Purple' cyclamen for 15 weeks in an ebb-and-flood system. The maximum test weight was 10 kg and containers receiving 10 kg in the figure exceeded the test limit and did not break. Peat and manure containers were already broken after 15 weeks and assigned a strength of zero. ns, *** Nonsignificant or significantly different from the plastic control at $P > F = 0.001$.

Fig. 4. Total fertilizer solution required to grow a 'Rainier Purple' cyclamen in 15.2-cm plastic containers or various biocontainers in an ebb-and-flood system. ns, * Nonsignificant or significantly different from the plastic control at $P > F = 0.05$.

analysis of variance and single-degree-of-freedom contrasts were conducted to determine if significant differences occurred between the plastic container and each of the biocontainers.

Results and Discussion

New container punch strength ranged from 19.3 N for the bottom zone of peat containers to 250.3 N for the bottom zone of coconut fiber containers (Fig. 1). The punch strengths of all zones of new coconut fiber containers were higher than those of new plastic containers. The top zone of new paper containers had a higher punch strength than the top zone of new plastic containers. However, the middle and bottom zones of the new paper and plastic containers had similar punch strengths. All other new biocontainers had lower punch strengths than the new plastic containers for all zones.

Used container punch strength ranged from 1.2 N for the bottom zone of peat containers to 269.8 N for the top zone of the paper containers (Fig. 2). The punch strength of the top zone of used paper containers was higher than the punch strength of the top zone of used plastic containers. However, the punch strengths of the middle and bottom zones of used paper containers were lower than the punch strengths of the corresponding zones of used plastic containers. All zones of all the other used biocontainers had lower punch strengths than the corresponding zones of used plastic containers.

Evans and Karcher (2004) and Evans et al. (2010) reported that plastic containers had the highest used punch strength of containers tested. This was the case for the bottom and middle zones of plastic containers in this experiment, but the top zone of the paper container had a higher punch strength than the corresponding zone of the plastic container. Evans and Karcher (2004) and Evans et al. (2010), however, did not evaluate punch strength of different zones but tested punch strength of a randomly selected area of the container wall. Additionally, in this experiment, larger container sizes and a subirrigation system were used in the evaluation of the containers. A key factor affecting used container strength was the ability of the container wall to absorb the fertilizer solution. This explains why the punch strength of the top zone of the paper containers was higher than the lower two zones. The paper container was the tallest container evaluated and the walls did not effectively absorb and wick water to the top zone. This resulted in the top zone remaining dry during the experiment and unaffected by the continued irrigation cycles. It also explains why the containers with the lowest punch strengths were the peat, dairy manure, and wood fiber containers. These containers readily absorbed and wicked water throughout the container wall. The plastic, paper, and coconut fiber containers increased in strength over the trial; it is suspected that when the punch test was conducted, those containers stretched before breaking.

A used strength of 15 N was proposed by the authors to be the minimum limit for handling and transporting containers without tearing based on handling of the wet containers. The peat, dairy manure, wood fiber, and rice straw containers had used punch strengths below 15 N for one or more zones. Therefore, handling, packaging, and shipping of these containers when used for the production of long-term crops using subirrigation systems could be problematic.

The tensile strength of all the new containers exceeded the testing limit of 10 kg, so all new biocontainers had similar tensile strengths as plastic containers in this study

(Fig. 3). The tensile strength of used biocontainers ranged from 0 kg for the peat and dairy manure containers (which were broken before testing) to 10 kg. The peat, dairy manure, rice straw, and wood fiber containers all had significantly lower used tensile strengths than the plastic containers. The bioplastic, solid ricehull, slotted ricehull, paper, and coconut fiber containers had similar used tensile strengths as the plastic containers.

To date, there have been no studies published on tensile strength of biocontainers. The dry strengths of the containers exceeded the testing limit and additional differences may have been observed if the testing limit was

Fig. 5. The average container, substrate and plant fertilizer solution absorption of 15.2-cm plastic containers and biocontainers in an ebb-and-flood system when used to grow 'Rainier Purple' cyclamen. NS, *, **, *** Nonsignificant or significantly different from the plastic control at $P > F = 0.05, 0.01, \text{ or } 0.001$, respectively, as compared with plastic.

Fig. 6. The irrigation interval of 15.2-cm plastic containers and various biocontainers in an ebb-and-flood system when used to grow 'Rainier Purple' cyclamen. Average irrigation interval was the mean number of days between irrigations. NS, * Nonsignificant or significantly different from the plastic control at $P > F = 0.05$.

higher. Although the used wood fiber and straw containers had tensile strengths below that of plastic, they were above the 2-kg limit for handling proposed by Evans et al. (2010). Peat and dairy manure containers broke during production and therefore were assigned tensile strengths of 0 kg. These containers, therefore, were not suitable for the production of long-term crops using subirrigation.

Total solution required to grow a single cyclamen plant for 15 weeks ranged from 15,746 mL for the plastic container to 24,189 mL for the wood fiber container (Fig. 4). The wood fiber containers required a higher amount of solution than the plastic containers to grow the cyclamen. All other containers required similar amounts of solution as the plastic container.

The average container solution absorption ranged from 140 mL for the wood fiber containers to 255 mL for the coconut fiber containers (Fig. 5). The coconut fiber container absorbed significantly more solution at each irrigation than the plastic containers although the wood fiber container absorbed less solution at each irrigation than the plastic container. All other containers absorbed similar amounts of solution as the plastic container.

The irrigation interval ranged from 0.6 d for the wood fiber container to 1.3 d for the plastic container (Fig. 6). The peat, dairy manure, wood fiber, and rice straw containers all had irrigation intervals that were shorter than the plastic container. The bioplastic, solid ricehull, slotted ricehull, paper, and coconut fiber containers all had irrigation intervals similar to the plastic containers.

In this study, containers with water-permeable walls such as peat, dairy manure, wood fiber, and rice straw had lower irrigation intervals and thus required more frequent irrigations than the plastic container. This was consistent with Evans et al. (2010) who reported that all containers except ricehull and bioplastic had shorter irrigation intervals than plastic containers. Evans et al. (2010) demonstrated that biocontainers with water-permeable walls lost water through the container wall at a higher rate than those with nonpermeable walls such as rice hull and plastic containers. Containers with water-permeable walls also required more total solution to produce the crop because more solution was lost as a result of evaporation through the container wall than in biocontainers with nonpermeable walls. Interestingly, the wood fiber container had the lowest irrigation interval, absorbed the least amount of water per irrigation, and required the highest amount of solution to grow the crop. This was because the wood fiber container did not have holes in the bottom or sides of the containers. Therefore, solution had to be absorbed by the container wall and then be absorbed by the substrate inside. This delayed the absorption of solution by the substrate and increased the amount of water lost by evaporation from the container walls.

The total container algal and fungal growth (AFG) ranged from a low of 0% coverage for the plastic, bioplastic, solid ricehull, and slotted ricehull containers to 85% for the

peat containers (Fig. 7). The paper, peat, dairy manure, wood fiber, rice straw, and coconut fiber containers had a higher total AFG than the plastic containers. The bioplastic, solid ricehull, and slotted ricehull containers all had the same total AFG as the plastic container. The AFG divided by zone ranged from 0% to 100%. All zones of bioplastic, solid ricehull, and slotted ricehull containers were similar to the plastic container (Fig. 8). The top zone of coconut fiber, the top zone of rice straw, and the top and middle zones of paper were all similar to corresponding zones of the plastic container. All other containers and zones had higher AFG than the corresponding zones of the plastic container.

The biocontainers that were the least permeable to fertilizer solution such as bioplastic

and rice hull containers had similar total amounts of AFG as the plastic containers, whereas those that readily absorbed the fertilizer solution into the container walls had higher total AFG than the plastic containers. This was consistent with the results of Evans et al. (2010) who attributed these results to that fact that container walls that readily absorbed the fertilizer solution provided a favorable environment for AFG. This also explains why the lower and middle zones of biocontainers typically had higher AFG than the top zone because the lower and middle zones would remain wet with fertilizer solution longer than the top zones.

Overall, the bioplastic, solid rice hull, slotted ricehull, paper, and coconut fiber biocontainers had properties that allowed

Fig. 7. Algal and fungal growth on container outer wall as a percentage of the entire outer container surface after being used to grow 'Rainier Purple' cyclamen for 15 weeks in an ebb-and-flood system. NS, *** Nonsignificant or significantly different from the plastic control at $P > F = 0.001$.

Fig. 8. Algal and fungal growth on container outer wall by zone as a percentage of the total area of that zone after being used to grow 'Rainier Purple' cyclamen for 15 weeks in an ebb-and-flood system. Bottom zone for all containers was 0 to 2 cm high. Middle and upper zones were determined by taking the remaining height of the container and dividing it in half creating two zones of equal height. NS, **, *** Nonsignificant or significantly different from the plastic control at $P > F = 0.01$ or 0.001 , respectively.

them to be suitable alternative to traditional plastic containers when used to grow long-term greenhouse crops on subirrigation systems. These containers retained high levels of punch and tensile strength, had little or no algal and fungal growth, and required similar amounts of fertilizer solution to grow the crop. The peat, dairy manure, wood fiber, and rice straw containers would not be appropriate substitutes for plastic containers in long-term

ebb-and-flood irrigation systems because of the low used strengths, high percentages of algae coverage, and shorter irrigation intervals.

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