Starch Tray with Addition of Different Components Foamed by Baking Process

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Abstract

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The possibilities of improving starch/water batter foam properties by additions of inorganic and organic compounds, waste sawdust and waste paper pulp were investigated. The most suitable ratio between starch and water was set to 2:3. The best results were obtained when calcium stearate was added to the starch/water tray because it filled the matrix of the tray and improved the surface. The addition of calcium stearate and a low amount of waste paper pulp and/or waste sawdust also brought good results. Higher amounts of waste sawdust and calcium stearate did not produce the compact and smooth surface of starch trays. The addition of polyvinyl alcohol improved these parameters.

Keywords: calcium stearate; foam; polyvinyl alcohol; potato starch; waste frass; waste paper pulp

Materials derived from agriculture are beginning to emerge as promising substitutes for petroleum-based plastics in a variety of applications including packaging, consumer non-durables, non-wovens, coatings, medical plastics, agricultural plastics, and textile fibres. Disposable products such as plastic tableware and packaging are targeted because they are generally used only once and are difficult to recycle. Petroleum-based plastics such as polyethylene and polystyrene foam may require hundreds of years to degrade and can kill wildlife if ingested. Though some of the synthetics are biodegradable and have excellent mechanical properties, they are currently expensive when compared with their nonbiodegradable counterparts. Due to the low initial costs and the advantage of being biodegradable into useful compost, the bio-based materials such as starch and cellulose can be considered as promising (Shogren *et al.* 1998, 2002; Lawton *et al.* 2004; Cinelli *et al.* 2006).

The utilisation of starch as a biodegradable, renewable base material for disposable articles such as plates, utensils, and bags is desirable as an environmentally friendly alternative to the current use of nondegradable, nonrenewable petroleum-based plastics (Shogren *et al.* 1998; Cinelli *et al.* 2006).

The research by Tiefenbacher (1993) has shown that starch/water batters can be baked in a closed, heated mould and thereby gelatinise and foam the starch into the shape of the mould. However, the use of this material as a substitute for plastics has been severely limited due to its brittleness and hydrophilicity. Subjects made from starch are weak and brittle at low humidity and swell and deform upon exposure to moisture, which is making them unsuitable for most packaging applications (Shogren *et al* 1998, 2002; Cinelli *et al.* 2006).

Duanmu *et al.* (2007) and Satyanarayana (2009) added mineral fillers and wood fibres to improve strength and coated plates with wax and other materials to improve water resistance. Water resistance and foam strength were improved by a coating with polyesters or polyvinyl alcohol (PVOH) added to the batter before baking. A water-resistant coating comprised of polyurethane and polyvinyl chloride was also described (Shogren *et al* 1998, 2002).

In this study, we have further investigated the possibilities of improving baked foam properties by additions of inorganic and organic compounds (calcium stearate, polyvinyl alcohol, etc.), waste paper pulp and waste sawdust. The effects of adding these components on the baking process parameters, strength, elongation to break and water resistance were determined.

MATERIAL AND METHODS

Material. Native potato starch, waste paper pulp from paper mill, waste spruce sawdust from sawmill, calcium stearate, polyvinyl alcohol (PVOH – 12.3 ± 1.0% of acetyl units), sodium triphosphate, pyrophosphate, pyrophosphate, stearic acid and starch modified with calcium stearate or stearic acid were used.

Preparation of batter. Potato native starch (30 g) and water (45 g) were mixed with a kitchen aid mixer in order to produce a homogeneous basic mixture. To prepare various types of trays, chosen types of inorganic and organic compounds or waste paper pulp or waste sawdust with starch/water batters were mixed at different ratio. After the addition of different amounts of compounds it was necessary to produce a compact tray. For this reason, the amount of starch and water was adjusted but their ratio remained unchanged 2:3 (starch to water).

Baking process. The starch foam trays with additives were prepared using a laboratory model baking machine (Institute of Chemical Technology Prague – ICT, Prague, Czech Republic). The top mould met the bottom mould during baking. The baking temperature of the top and bottom moulds was set at 200°C. The starch batter was inserted between the opened heated moulds. The moulds were closed and the batter baked into trays. Enough batter was drawn up into the syringe and dispensed into the mould so that after foaming, the starch just filled the mould and formed a complete tray of 8 × 4 cm. After baking, the samples of trays were adjusted to the size of 2.5 × 5 cm or 3 × 5 cm.

Determination of vapour sorption. A desiccator with water was equilibrated at ambient temperature for 24 hours. After that 95% relative humidity (RH) was established inside. Trays were taken into the desiccator and the amount of sorbed water was measured after 1, 3, 5, and 24 h by tray weighting. The amount was calculated in percentage (%) and/or in grams per square area (g/dm^2).

Mechanical testing. After the baking process, the trays were adjusted to the size of 2.5 × 5 cm. Mechanical properties of the adjusted trays were measured with an Instron, Model 5544 (INSTRON Ltd., Bucks, UK). The testing samples were placed onto the machine supports and there the plunger pressed the trays at a velocity of 30 mm/min to the beginning of permanent deformation. Maximum power (N) needed for the permanent deformation was measured.

RESULTS AND DISCUSSION

Food contains water in different amounts and should be in direct contact with the packaging. Water has an influence on the structure and functional properties of food packaging. The packages on the starch base are very sensitive to water. This is caused by the hydrophilicity of starch molecules and porous structure of starch packages.

The main aim of this research was to improve the properties of the baked starch mould. Starch/water mixture batters with various additives of inorganic and organic compounds, waste paper pulp and waste sawdust were investigated. The assumption was that the additions of different components would fill the matrix of the tray and avoid the water infiltration into the structure of the tray.

An appropriate ratio of starch and water to form the compact and complete trays had to be determined. The relationship between potato starch and water was established to the ratio of 2:3 (starch to water).

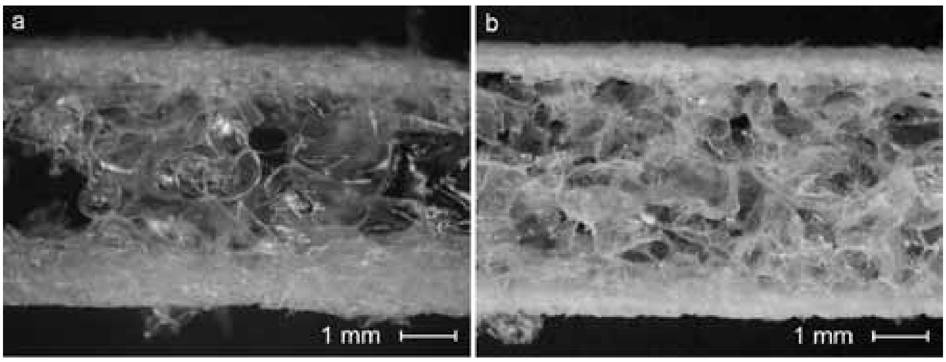

Figure 1. Inner structure of (**a**) basic starch tray and (**b**) tray with addition of 2% of calcium stearate

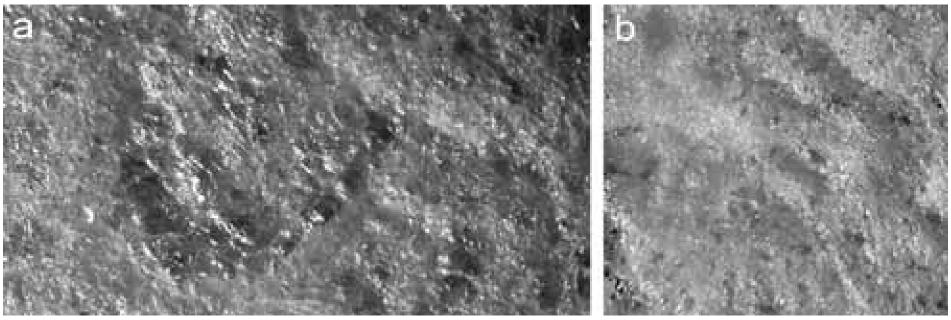

Figure 2. Surface structure of (**a**) basic starch tray and (**b**) tray with addition of 2% of calcium stearate

After that, the addition of compounds which are able to eliminate the influence of hydrophilic hydroxyl groups of starch was tested. These additives have one or two reactive groups. The addition of calcium stearate filled the matrix of the tray (Figure 1); the surface of this tray became smoother (Figure 2) than the basic tray (starch/water). Thanks to the high temperature during the baking process, calcium stearate can potentially react with starch hydroxyl groups to make esters; the produced starch foam is compact and resistant to water vapour. If stearic acid was the only additive, it showed a low influence on the quality of trays, the water vapour infiltration was significantly higher (Figure 3). The additions of inorganic compounds, sodium triphosphate, and pyrophosphate, affected the disintegration and gelation of trays positively, but the improvement in hydrophobicity of starch foam was not as significant as when calcium stearate was added (Figure 3).

It was supposed that the addition of waste paper pulp would improve the mechanical properties only because of the fact that the cellulose, like the basic component of paper pulp, is quite hydrophilic. However, the molecules of cellulose filled the tray matrix too much and the final hydrophobicity of

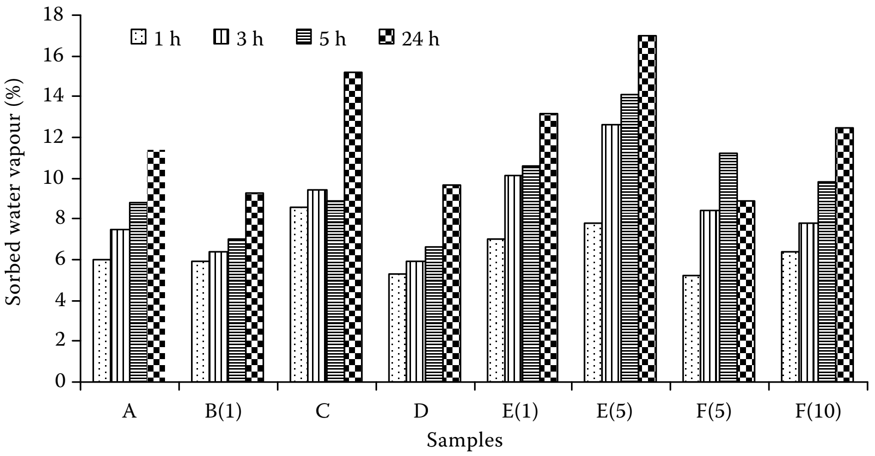

Figure 3. Measurement of amount of sorbed water vapour to chosen starch/water trays with additives (for sample specification see Table 1)

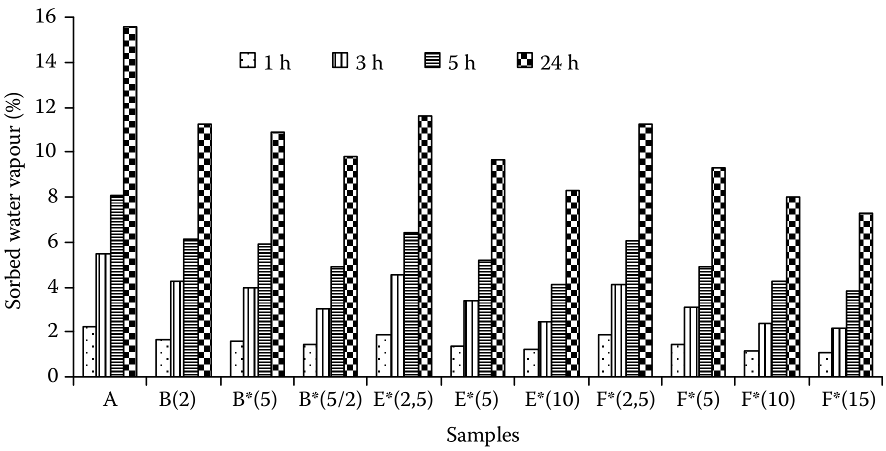

Figure 4. Measurement of amount of sorbed water vapour to chosen starch/water trays with additives (for sample specification see Table 1)

Table 1. Specification of samples used in Figure 1–4

Samples	Description of sample
A	starch/water mixture
B(1)	starch/water mixture with 1% of calcium stearate
B(2)	starch/water mixture with 2% of calcium stearate
C	starch/water mixture with 1% of sodium triphosphate
D	starch/water mixture with 1% of pyrophosphate
E(1)	starch/water mixture with 1% of stearic acid
E(5)	starch/water mixture with 5% of stearic acid
F(5)	starch/water mixture with 5% of starch modified with calcium stearate
F(10)	starch/water mixture with 10% of starch modified with stearic acid
E*(2.5)	starch/water mixture with 2.5% of waste sawdust
E*(5)	starch/water mixture with 5% of waste sawdust
E*(10)	starch/water mixture with 10% of waste sawdust
F*(2.5)	starch/water mixture with 2.5% of waste sawdust and 2% of calcium stearate
F*(5)	starch/water mixture with 5% of waste sawdust and 2% of calcium stearate
F*(10)	starch/water mixture with 10% of waste sawdust and 2% of calcium stearate
F*(15)	starch/water mixture with 15% of waste sawdust and 2% of calcium stearate
A-5% PVOH	starch/water mixture with 5% of polyvinyl alcohol
A-10% PVOH	starch/water mixture with 10% of polyvinyl alcohol
A-15% PVOH	starch/water mixture with 15% of polyvinyl alcohol
A-20% PVOH	starch/water mixture with 20% of polyvinyl alcohol
B(2)	starch/water mixture with 2% of calcium stearate
B(2)-5% PVOH	starch/water mixture with 2% of calcium stearate and 5% of PVOH
B(2)-10% PVOH	starch/water mixture with 2% of calcium stearate and 10% of PVOH
B(2)-15% PVOH	starch/water mixture with 2% of calcium stearate and 15% of PVOH
B(2)-20% PVOH	starch/water mixture with 2% of calcium stearate and 20% of PVOH
B*(5)	starch/water mixture with 5% of waste paper pulp
B*(5)-5% PVOH	starch/water mixture with 5% of waste paper pulp and 5% of PVOH
B*(5)-10% PVOH	starch/water mixture with 5% of waste paper pulp and 10% of PVOH
B*(5)-15% PVOH	starch/water mixture with 5% of waste paper pulp and 15% of PVOH
B*(5/2)	starch/water mixture with 5% of waste paper pulp and 2% of calcium stearate
B*(5/2)-5% PVOH	starch/water mixture with 5% of waste paper pulp and 2% of calcium stearate and 5% of PVOH
B*(5/2)-10% PVOH	starch/water mixture with 5% of waste paper pulp and 2% of calcium stearate and 10% of PVOH
B*(5/2)-15% PVOH	starch/water mixture with 5% of waste paper pulp and 2% of calcium stearate and 15% of PVOH
B*(5/2)-20% PVOH	starch/water mixture with 5% of waste paper pulp and 2% of calcium stearate and 20% of PVOH
F*(10)	starch/water mixture with 10% of waste sawdust and 2% of calcium stearate
F*(10)-5% PVOH	starch/water mixture with 10% of waste sawdust and 2% of calcium stearate and 5% of PVOH
F*(10)-10% PVOH	starch/water mixture with 10% of waste sawdust and 2% of calcium stearate and 10% of PVOH
F*(15)	starch/water mixture with 15% of waste sawdust and 2% of calcium stearate
F*(15)-5% PVOH	starch/water mixture with 15% of waste sawdust and 2% of calcium stearate and 5% of PVOH
F*(15)-10% PVOH	starch/water mixture with 15% of waste sawdust and 2% of calcium stearate and 10% of PVOH

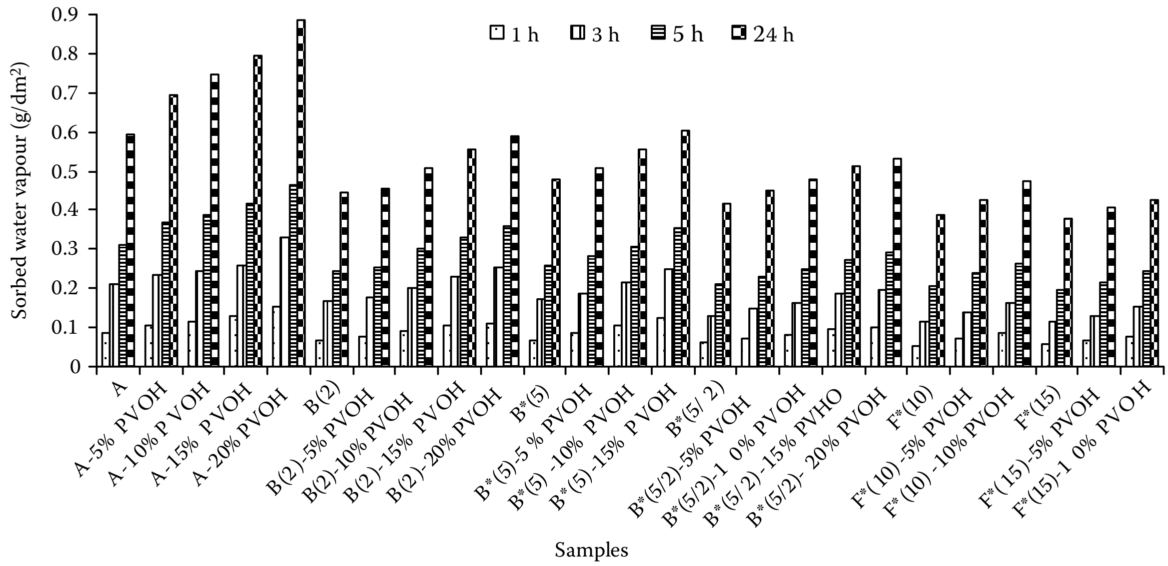

Figure 5. Measurement of amount of sorbed water vapour to chosen starch/water trays with additives (for sample specification see Table 1)

starch packaging materials was better than the starch/water tray itself (Figure 4). The addition of a higher amount of waste paper pulp resulted in non-compact trays, their surfaces were not homogeneous. The best solution was to add calcium stearate and a lower amount of waste paper pulp to the starch/water batter.

Another test additive, which was added to the structure of starch trays, was waste sawdust. The components of waste sawdust are bigger in contrast to waste paper pulp and contain the incrustation compounds – lignin and hemicelluloses – which could positively influence the mechanical and sorption properties. The allowance of a small batch of waste sawdust made the structure non-homogeneous and the sawdust did not fill the matrix and sorption properties were unsatisfactory (Figure 4). If we tried to add more waste sawdust with a small amount of calcium stearate, 10% better sorption properties were measured than in the trays with 5% of waste paper pulp and 2% of calcium stearate. However, higher amounts of waste sawdust and calcium stearate did not produce so compact and smooth surface of the starch trays. The starch tray containing 15% of waste sawdust and 2% of calcium stearate (Figure 4) appeared to be the best sample to be tested in the next measuring.

Polyvinyl alcohol (PVOH) was the last additive to be tested. This polymer was added to the matrix of starch trays in order to improve mechanical and sorption properties as Shogren *et al.* (1998)

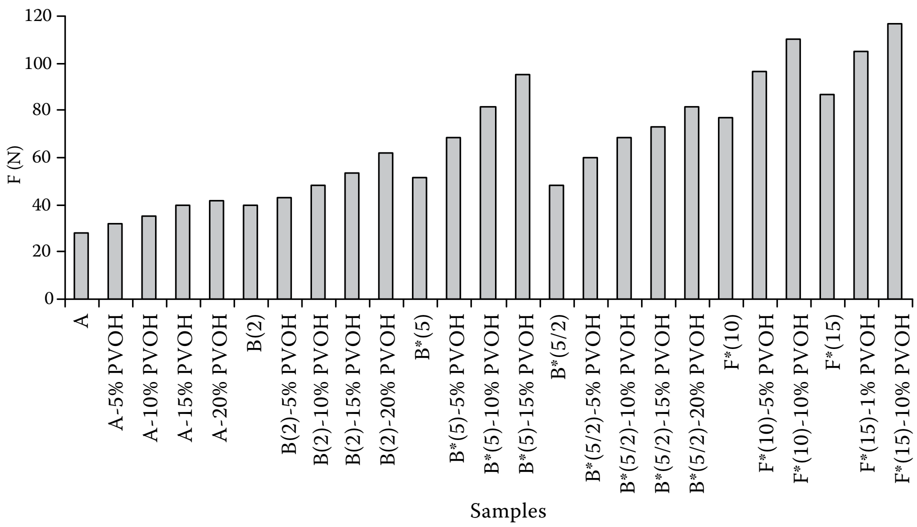

Figure 6. Measurement of mechanical properties of chosen starch/water trays with additives (for sample specification see Table 1)

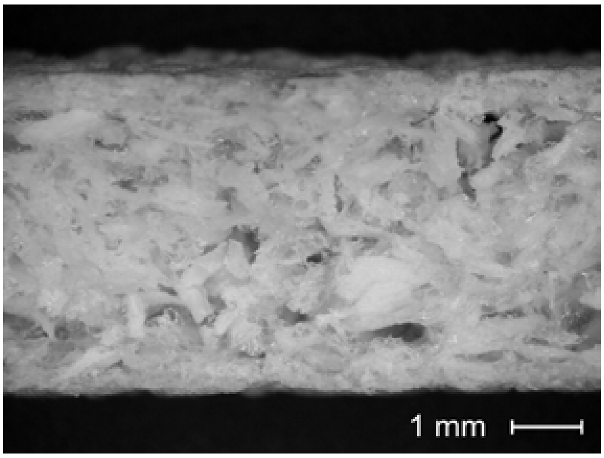

Figure 7. Inner structure of tray with addition of 15% of waste frass, 2% of calcium stearate and 5% of PVOH

described. Thanks to the addition of PVOH into the starch/water batters, a more compact and smoother surface was obtained (Figure 5) than in the preceding experiments, but the matrix of the tray was not uniform. Better results were attained if calcium stearate and waste paper pulp or waste sawdust were mixed. In this case, the whole structure of the tray was filled in. The structure of a tray showed better results after a small amount (5%) of PVOH had been added. According to Figure 5, it was significant that a higher amount of PVOH increased the sorption of water vapour. The smallest amount of sorbed water was measured in the tray with the content of 5% of PVOH, 2% of calcium stearate, and 15% of waste sawdust.

The addition of PVOH brought significant results in mechanical properties of prepared trays with additives (Figure 6). 5% of PVOH added to the trays with a content of waste paper pulp and waste sawdust resulted in the stabilization of the internal structure (Figure 7) and thus significantly improved mechanical properties of the trays. Thanks to the addition of 5% of PVOH into the basic starch-water tray, the mechanical properties of these trays were similar. However, if the same amount of PVOH was added into the tray with 2% of calcium stearate and 15% of waste sawdust, the mechanical properties increased by approximately 20%.

CONCLUSION

Starch trays with advanced resistance to water vapour and higher mechanical stability were prepared by the addition of calcium stearate, waste paper pulp, waste sawdust, and polyvinyl alcohol. These trays are very promising for use in the food industry as packaging materials. The chance for the practical application of these materials is given not only by improved mechanical and physical properties but also by the fact that the waste as the secondary raw materials is used for their preparation.

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