The antifungal activity of potassium silicate and the role of pH against selected plant pathogenic fungi *in vitro*

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In-vitro inhibition of mycelial growth of phytopathogenic fungi grown on potassium silicate amended media has been demonstrated. In the current study the respective effects on fungal growth of changes in the pH of growth medium with increased concentrations of potassium silicate, and potassium silicate concentrations *per se* were investigated. To assess the effect of pH on mycelial growth, PDA was adjusted to pH's (10.3–11.7) similar to those associated with potassium silicate concentrations (20–80 ml.l^{-1} potassium silicate; 20.7% silicon dioxide) using KOH. Inhibition of mycelial growth was dose-related with 100% inhibition at concentrations > 40 ml (pH 11.5) soluble potassium silicate per litre of agar. Inhibition of mycelial growth on KOH amended PDA ranged from 0–100% and the effect of pH on mycelial growth was inconsistent. Although soluble potassium silicate has a two-fold effect on fungal growth *in vitro*, the direct inhibitory effect clearly overrides the effect of pH.

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Biggs *et al*. (1997) reported a 65% growth reduction of *Monilinia fructicola* (G.Wint.) Honey, the causal fungus of brown rot of peach fruit, on Potato Dextrose Agar (PDA) amended with calcium silicate compared to control treatments. Bekker *et al*. (2006) reported *in-vitro* inhibition of mycelial growth of several phytopathogenic fungi grown on potassium silicate amended media. Menzies *et al*. (1992) studied the *in vitro* effect of silicon on conidial germination and germ tube growth of powdery mildew (*Erysiphe cichoracearum* and *Sphaerotheca fuliginea*) on cucurbits and concluded that potassium silicate had no effect on either factors tested. The effect of potassium silicate on mycelial growth was however not mentioned. Wainwright *et al*. (1994) reported that, although fungal mycelia formed when inoculum was placed on nutrient free silica gel, no mycelia could be found on the gel surface and growth was therefore most probably supported by nutrients from the inoculum.

Concentrated soluble potassium silicate has a pH of 12.7, which increases the pH of an ameliorated PDA media. Unamended PDA has a pH of 5.6 but upon addition of 5 to 80 ml soluble potassium silicate per litre of agar, is raised to 10.3 to 11.7, respectively (Bekker *et al*., 2006). The present study examined the respective effects on fungal growth of changes in the pH of growth medium with increased concentrations of potassium silicate, and potassium silicate concentrations *per se*. *In vitro* responses to potassium silicate (20.7% silicon dioxide) concentration and pH were determined for 11 pathogenic fungi (Table 1).

Fungal isolates maintained on PDA were obtained from various plant pathogen laboratories (Bekker, 2007) and were selected on the basis of availability of cultures and their importance as plant pathogens.

Potassium silicate was passed through a 0.45 µm Millipore filter and added to PDA after it had cooled to 60ºC. PDA was amended with five concentrations of potassium silicate (Table 1) and stirred continuously with magnetic stirrers to ensure even distribution of potassium silicate, and then decanted into Petri dishes. To assess the effect of pH on mycelial growth, PDA was adjusted to pH's concomitant with those associated with potassium silicate concentrations i.e. 10.3, 10.7, 11.2, 11.5 and 11.7 using KOH, and agar was aseptically dispensed into 9 cm diameter plastic Petri dishes. A 5 mm diameter mycelial disc taken from a seven-day-old PDA-culture of the respective test fungus was transferred to the centre of a Petri dish containing PDA either amended with soluble potassium silicate or potassium hydroxide, or unamended control plates. Ten replicates were included for each treatment. Plates were incubated at 25°C in the dark and colony diameters were measured every second day for eight days. The experiment was repeated and results were pooled. Data were subjected to two-way analyses of variance (ANOVA) with pH plates as co-variant to determine silicon effects, while mean differences were separated according to Duncan's multiple range test ($P < 0.05$).

Soluble potassium silicate inhibited all mycelial growth of *Phytophthora cinnamomi* and *Phytophthora capsicii* at all concentrations tested (Table 1). All fungal growth was suppressed at concentrations > 40 ml l^{-1} potassium silicate but fungi differed in their tolerance thresholds (Table 1) implying differences in the sensitivity of fungi to potassium silicate and the effective inhibition concentrations. Results indicate the suppressive effect that soluble potassium silicate has on fungal mycelial growth.

Inhibition of mycelial growth on KOH amended PDA ranged from 0–100% (Table 1) and at some pH levels, pathogen growth was enhanced e.g. *Alternaria solani* growth was 13.8% faster at pH 11.2 (Table 1) compared to the control. The effect of pH on mycelial growth was, however, inconsistent. As a result, it may be concluded that potassium silicate has a direct inhibitory effect on mycelial growth and the observed inhibition is not primarily as a result of the potassium silicate changing the pH of the medium. In all fungi tested, mycelial growth continued at high pH values in the absence of potassium silicate, albeit at a slower rate. However, results also imply that soluble potassium silicate has a two-fold effect on fungal growth.

Wainwright (1993) suggested nutrient-free silica gel supports fungal growth, with the gel itself acting as a nutrient source and stimulating spore formation. Visible mycelial growth was reported by Wainwright *et al*. (1997) to be present on silicic acid amended media. They however ascribed this growth to silicon acting only as a physical contact surface for spores, rather than acting as a nutrient source.

Low potassium silicate concentrations resulted in increased

Table 1 Mean percentage inhibition of fungi due to potassium silicate (20.7% silicon dioxide) or potassium hydroxide concentration on ameliorated PDA incubated at 25ºC for 8 days

		Percentage inhibition										
		Amended potassium silicate					Amended potassium hydroxide					
Pathogen	Isolate no.	5 ml Si (pH 10.3)	10 ml Si (pH 10.7)	20 ml Si (pH 11.2)	40 ml Si (pH 11.5)	80 ml Si (pH 11.7)	pH 10.3	pH 10.7	pH 11.2	pH 11.5	pH 11.7	Pr.F.
Alternaria solani Sorauer	UPGH100	22.9c	100.0e	100.0e	100.0e	100.0e	33.5d	11.8b	-13.8a	-13.0a	24.8c	< 0.001
Colletotrichum gloeosporioides (Penz.) Penz. & Sacc.	PPRI3848	15.7a	76.4d	100.0e	100.0e	100.0e	20.4b	17.1a	16.2a	26.5b	57.8c	< 0.001
Fusarium oxysporum Schltdl. W. Snyder & H.N. Hansen	UPGH110	-8.2a	23.7c	96.2d	100.0e	100.0e	-8.2a	-8.2a	-8.2a	-8.2a	-2.3b	< 0.001
Glomerella cingulata (Stoneman) Spauld. & H. Schrenk	PPRI6360	9.3b	79.7e	100.0f	100.0f	100.0f	0.0a	0.0a	9.3b	14.0c	32.0d	< 0.001
Lasiodiplodia theobromae (Pat.) Griffon & Maubl.	PPRI6630	11.3b	100.0d	100.0d	100.0d	100.0d	0.0a	0.0a	0.0a	0.0a	43.0c	< 0.001
Natrassia sp.	PPRI6718	46.4e	100.0f	100.0f	100.0	f 100.0f	8.4b	22.5c	0.0a	19.0c	34.0d	< 0.001
Pestaliopsis maculans (Spreg.) Steyaert	PPRI5564	23.6b	100.0e	100.0e	100.0e	100.0e	18.3b	7.7a	14.3ab	44.0c	77.0d	< 0.001
Phomopsis perseae Zerova	PPRI6005	41.8e	100.0g	100.0g	100.0g	100.0g	4.6a	13.6b	18.8c	34.9d	64.7f	< 0.001
Phytophthora capsicii Leonian	UPGH118	100.0d	100.0d	100.0d	100.0d	100.0d	22.0a	31.8b	19.4a	47.7c	49.9c	< 0.001
Phytophthora cinnamomi Rands	-	100.0a	100.0a	100.0a	100.0a	100.0a	100.0a	100.0a	100.0a	100.0a	100.0a	< 0.001
Pythium F-group	UPGH009	32.9b	100.0d	100.0d	100.0d	100.0d	0.0a	0.0a	0.0a	0.0a	96.7c	< 0.001

fungal growth of *Fusarium oxysporum* (-8.2% inhibition at 5 ml.l^{-1} potassium silicate) (Table 1). This phenomenon was observed in numerous fungi by Wainwright *et al.* (1997). It is possible that silicon at sub-toxic concentrations could act as a nutrient supplement and induce faster mycelial growth. However, results indicate that where mycelia were induced to grow faster with low concentrations of silicon, the corresponding pH control groups showed similar growth patterns. It is thus likely that faster mycelial growth in certain fungi is due to an affinity for higher pH growing conditions, and not due to a possible nutrient supplement effect. By implication, if silicon is used as a fungicide, it could, at certain concentrations, create conditions conductive to the growth of these fungi.

Soluble potassium silicate completely suppresses mycelial growth of all fungi tested at concentrations of 40 and 80 ml l^{-1} potassium silicate. Although soluble potassium silicate has a two-fold effect on fungal growth, the direct effect overrides the effect of pH. The inclusion of KOH as a control treatment eliminated any potential role potassium may play in enhancing or suppressing mycelial fungal growth. It is proposed that silicon may act as the first protecting barrier in silicon treated plants, and may inhibit pathogen colonisation and consequential infection by inhibiting fungal growth on the plant surface.

These results are important when potassium silicate is used as a fungicide, as it indicates that potassium silicate has a direct inhibitory influence on fungal growth in addition to its ability to increase the plants' host defence system (Menzies *et al*., 1992) or strengthening plant cell walls, inhibiting infection (Epstein, 1999).

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