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STROBILURINS INFLUENCE MORPHOLOGICAL CHARACTERS AND YIELD IN CHILLI (*Capsicum annum* L.)

S. Punitha, A. Senthil* and P. Jeyakumar

Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore – 641 003, Tamil Nadu (India)
*e-mail: *senthil.a@tnau.ac.in*

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ABSTRACT

The present study was aimed to assess the influence of strobilurin fungicides on non-fungicidal physiological characters *viz*., root length, plant height, number of branches, leaf area and total dry matter accumulation in chilli (*Capsicum annum*). The experiment was laid out in a randomized block design and comprised of seven treatments of various concentrations of strobulin fungicides trifloxystrobin and tebuconazole. The plant height was significantly reduced in all the strobilurin fungicidal treatments as compared to the untreated control. Pyraclostrobin in combination with metiram @ 1500 g ha^{-1} reduced plant height by 12% over untreated control. The application of trifloxystrobin + tebuconazole @ 400 g ha^{-1} gave longer roots, more number of branches and higher total dry matter accumulation. Further, it gave maximum green chilli yield (20.44 t ha^{-1}) with 13% increase over untreated control (15.26 t ha^{-1}).

Key words: Chilli, dry matter production, leaf area, plant height, root length, strobilurins, yield

INTRODUCTION

Chilli (*Capsicum annum* L.) has originated from Latin America and is currently used as a spice throughout the world as well as for preparing beverages and medicines. The chilli fruit is rich in vitamin A, C and E, and its powder has some unique medicinal properties. Capsaicin in chilli fruits imparts pungency. The world production of chilli presently is around 7 million tones, cultivated on approximately 1.5 million ha area (Manish Kumar, 2016). India is a leading chilli producing and exporting country in the world followed by China and Pakistan (NPCS, 2013). World-wide chilli accounts about 16% of total spice trade so occupies 2nd position after black pepper (NABARD, 2014).

Chilli crop suffers from various production constraints including the diseases caused by fungi, bacteria and viruses. Among the fungal diseases, powdery mildew, Cercospora leaf spot and anthracnose are most prevalent diseases in chilli in India causing severe defoliation and reduction in the size and number of fruits thereby inflicting yield losses of about 14-20% (Ahila Devi and Prakasam, 2014). These diseases have effectively been controlled by using various agro-chemicals; however indiscriminate use of same chemicals adversely affects soil fertility, increases toxicity, promotes pest and disease resurgence and causes health and environmental hazards **(**Kumar and Singh, 2015). Hence, advocacy of modern agro-chemicals is emphasized which are comparatively safer and enhance crop growth and yield, in addition to pest and disease management. Considering the ever increasing demand for food production with shrinking cultivable lands, it is imperative to use such agrochemicals which enhance plant growth and development vis-à-vis productivity (Kanungo and Joshi, 2014). Strobilurins (trifloxystrobin, azoxystrobin, pyraclostrobin, kresoxim methyl, etc.) and triazoles (propiconazole, epoxiconazole, tebuconazole, penconazole, etc.) have changed the concept of disease control and some positive physiological effects in addition to the disease control (Debashis *et al*., 2012). The studies so far have concentrated on phytohormone-mediated effects of strobilurins on the physiology of plant senescence process (Mansi and Juhie, 2014). A longer photosynthetic period for active green leaf area has been suggested to be the main factor for yield increase due to strobilurin fungicides as the increase in photosynthetic period would increase the quantity of assimilate available for grain filling (Bertelsen *et al.*, 2001).

There is increasing evidence that strobilurins directly affect plant physiology and exert "greening" effect i.e. even in the absence of challenge by pathogenic attack, plants treated with strobilurins look intense green and healthier than untreated plants (Kyveryga *et al.*, 2013). This suggests that, in addition to the biocidal activity, strobilurins enhance the ability of plants to ward off the pathogens. Several strobilurin fungicides are known to exhibit growth-promoting effects in various plants. The combined use of strobilurin and triazole fungicides reportedly influences various morpho-physiological traits in corn, soybean, wheat, etc. (Reddy, 2013). These fungicides may inhibit plant growth, decrease intermodal elongation, increase chlorophyll content, enlarge chloroplast, thicken leaf tissue, increase root to shoot ratio, delay senescence, increase antioxidant potential and enhance alkaloid production (Zhang *et al*., 2010). Strobilurins reportedly affect yields in wheat, corn and soybean (Nelson and Meinhardt, 2011; Hill *et al.*, 2013). Ruske *et al.* (2003) reported higher biomass production and grain yield due to strobilurins. The present study was aimed to assess the effect of strobilurins applied in conjunction with other fungicides (triazoles and dithiocarbomates) on morphological traits and yield of chilli crop.

MATERIALS AND METHODS

A field trial was conducted to assess the influence of various formulations of strobilurins on morphological parameters of chilli crop during *kharif* 2014 in TNAU, Coimbatore (India). Chilli hybrid 'Mahi' having duration of 150 days was used in this study. The experiment consisted of seven treatments with different concentrations of strobilurin formulations *viz.*, trifloxystrobin + tebuconazole (Nativo) @ 300, 350 and 400 g ha^{-1}, pyraclostrobin + metiram (Cabriotop) @ 1500 g ha^{-1} and azoxystrobin (Amistar) @ 500 mL ha^{-1}, along with carbendazim @ 500 g ha^{-1} and untreated control. The trial was laid in a randomized block design with four replications in a plot size of 5 x 4 m and maintained at plant spacing of 75 x 60 cm. The NPK was applied @ 120:80:80 kg ha^{-1}. The nitrogen, phosphorus and potassium were applied in the form of urea, single super phosphate and muriate of potash, respectively. Full dose of P and K was applied as basal and 1/4th nitrogen (30 kg) at the time of transplantation and remaining given 30, 60 and 90 days after transplanting (DAT) as equal dose. Light irrigation was given on 3rd day after transplantation. Gap filling was done on 7th day after transplantation. Manual weeding was done regularly and irrigation given at weekly interval. Chlorpyriphos @ 2 mL L^{-1} was sprayed to control aphids and thrips as and when required.

The treatments were applied as foliar spray twice at 45 and 60 DAT. Observations on root length, plant height, number of branches, leaf area and total dry matter accumulation were recorded on 30, 60, 90 and 120 DAT. The plant height was measured from the base of shoot to the longest leaf. The root length of each plant was measured from collar region to the tip of lengthiest root. The number of branches was counted in five randomly selected plants from each plot. Leaf area $plant^{-1}$ was measured using a leaf area meter (LICOR, Model LI 3000). The plants were uprooted along with intact root system at different stages and separated into leaf, stem and root portions to estimate total dry matter (TDM). The plant parts were weighed separately after drying them at 80±2°C for 48 hr in a hot air oven. The TDM production was arrived by summing up the dry weights of leaf, stem and root. The yield and yield parameters were assessed by tagging ten plants from each replication and treatment and measured periodically from the tagged plants. The incidence of leaf spots was assessed using 0-9 scale of standard score chart and the percent disease index was calculated using McKinney's (1923) formula. The data were analyzed using analysis of variance as per the procedure of Gomez and Gomez (1984).

RESULTS AND DISCUSSION

The application of fungicides on chilli crop resulted in significantly affected root length, plant height, number of branches, leaf area and total dry matter accumulation. Root characters such as length and distribution help in divulging the pattern of water use and nutrition uptake by the crop. Among the treatments, a maximum of 26.58% increase in root length over control was observed in treatment trifloxystrobin + tebuconazole @ 400 g ha^{-1} which had highest root length of 29.74 cm, followed by pyraclostrobin + metiram @ 1500 g ha^{-1} with root length of 28.35 cm (Fig. 1). The increased root length in treatment trifloxystrobin + tebuconazole @ 400 g ha^{-1} appears to have facilitated water and nutrient absorption from soil, which are crucial factors affecting crop growth (Nagajothi and Jeyakumar, 2014). In turfgrass, significant increase in total root length and root biomass had been observed in the plants treated with pyraclostrobin (Sundravadana *et al.*, 2008). Venancio *et al.* (2003) suggested that strobilurin treated turfgrass display a response similar to low doses of auxin, a plant growth hormone known to promote adventitious rooting. The combination of azoxystrobin and epoxiconazole applied at flag leaf emergence enhanced root length and biomass in wheat (Ford *et al.*, 2006). In present study also the combination of strobilurins and triazole compounds proved better in improving root length as compared to control. The increased root length seems due to the inhibition of gibberellic acid synthesis causing reduced shoot length and increased partitioning of assimilates towards roots due to strobilurins and triazoles. Paclobutrazol increased the diameter and length of fibrous roots and enhanced lateral root formation in tomato (Berova *et al.*, 2002). Root growth stimulation by triazoles has also reported by Yelenosky *et al.* (1995) in citrus.

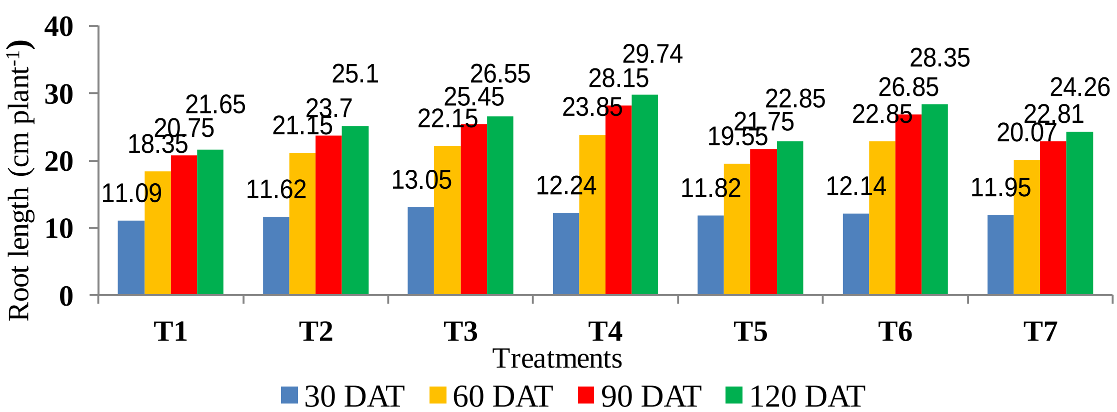

Fig. 1: Effect of strobilurin fungicides on root length (cm) at different growth stages of chilli

T_1 - Untreated control; T_2 - Trifloxystrobin + tebuconazole @ 300 g ha^{-1}; T_3 - Trifloxystrobin + tebuconazole @ 350 g ha^{-1}; T_4 – Trifloxystrobin + tebuconazole @ 400 g ha^{-1}; T_5 - Carbendazim 50 WP @ 500 g ha^{-1}; T_6 - Pyraclostrobin + metiram 60 WG @ 1500 g ha^{-1}; T_7 - Azoxystrobin 23 SC @ 500 mL ha^{-1}

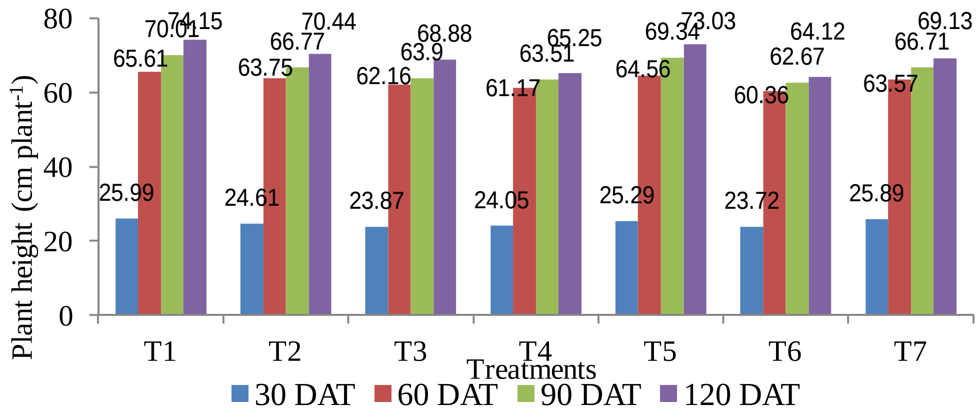

Fig. 2: Effect of strobilurin on plant height at different growth stages of chilli T_1 - Untreated control; T_2 - Trifloxystrobin + tebuconazole @ 300 g ha^{-1}; T_3 - Trifloxystrobin + tebuconazole @ 350 g ha^{-1}; T_4 - Trifloxystrobin + tebuconazole @ 400 g ha^{-1}; T_5 - Carbendazim 50 WP @ 500 g ha^{-1}; T_6 - Pyraclostrobin + metiram 60 WG @ 1500 g ha^{-1}; T_7 - Azoxystrobin 23 SC @ 500 mL ha^{-1}

Plant height is an important morphological character that reflects the growth and development of a crop. In present study the plant height was significantly reduced by fungicides use. Pyraclostrobin + metiram 60WG @ 1500 g ha^{-1} reduced plant height by 12% (Fig. 2). Izumi *et al.* (1984) and Gopi *et al.* (1999) attributed similar reduction in rice and cowpea to the inhibition of cell expansion by pyraclostrobin. The use of strobilurin + triazole induced various morpho-physiological changes in rapeseed including decrease in inter-nodal elongation and plant height (Ruske *et al.*, 2003). Swoboda and Pedersen (2009) have reported that foliar application of pyraclostrobin alone or in combination with tebuconazole reduced plant height in soybean. Zhang *et al.* (2010) noticed a steady decline in soybean plant height when sprayed with strobilurins and triazole. Plant height was significantly altered by use of anti-gibberellin, triazole fungicides and growth regulator trinexapac alone and in combination with strobilurin in oilseed rape and short statured plants were obtained when tebuconazole and metconazole were applied (Muhammad Ijaz, 2012). The gibberellins are associated with plant growth and development processes such as stem and hypocotyls elongation, leaf expansion, etc. (Akazawa *et al.*, 1990). Strobulin fungicides cause inhibition of gibberellin synthesis and cell expansion and reduce stem elongation (Scarisbrick *et al*., 1985).

The number of branches plant^{-1} increased with increase in growth period, irrespective of treatments (Table 1). All the treatments had significantly higher number of branches plant^{-1} as compared to control. The number of branches plant^{-1} was highest in trifloxystrobin + tebuconazole 75 WG @ 400 g ha^{-1} (59.0) treated plants and minimum in control (37.8) at 120 DAT. These findings are in agreement with Bertelsen *et al.* (2001) who reported inhibition in stem growth due to the application of triazoles and strobilurins in winter rapeseed as a result of alteration in canopy architecture and improved lateral and auxiliary buds formation.

Table 1: Effect of strobilurin on the number of branches plant^{-1} at various growth stages in chilli

Treatments	30 DAT	60 DAT	90 DAT	120 DAT
Untreated control	9.4	30.0	33.8	37.8
Trifloxystrobin + tebuconazole @ 300 g ha^{-1}	9.1	32.8	45.7	49.5
Trifloxystrobin + tebuconazole @ 350 g ha^{-1}	8.8	35.1	46.2	50.7
Trifloxystrobin + tebuconazole @ 400 g ha^{-1}	9.5	38.6	51.8	59.0
Carbendazim 50 WP @ 500 g ha^{-1}	9.0	31.1	36.6	40.7
Pyraclostrobin + metiram 60 WG @ 1500 g ha^{-1}	9.8	36.4	48.0	53.4
Azoxystrobin 23 SC @ 500 mL ha^{-1}	10.1	31.8	40.2	43.9
Mean	9.4	33.7	43.2	47.8
S.E.	0.08	0.30	0.39	0.44
$CD_{0.05}$	ns	0.61	0.80	0.89

Table 2: Effect of strobilurin on leaf area (cm^2 $plant^{-1}$) at different growth stages in chilli

Treatments	30 DAT	60 DAT	90 DAT	120 DAT
Untreated control	235.43	1514.72	3105.65	897.57
Trifloxystrobin + Tebuconazole @ 300 g ha^{-1}	216.49	1873.01	3367.08	1021.06
Trifloxystrobin + Tebuconazole @ 350 g ha^{-1}	234.62	2180.14	3515.41	1041.52
Trifloxystrobin + Tebuconazole @ 400 g ha^{-1}	227.13	2369.33	3601.07	1067.01
Carbendazim 50 WP @ 500 g ha^{-1}	219.09	1604.54	3134.34	949.12
Pyraclostrobin + metiram 60 WG @ 1500 g ha^{-1}	225.45	2518.05	3901.56	1231.46
Azoxystrobin 23 SC @ 500 mL ha^{-1}	211.26	1776.63	3291.76	998.09
Mean	224.21	1976.63	3416.70	1029.40
S.E.	2.13	18.99	31.61	9.59
$CD_{0.05}$	ns	38.42	63.94	19.41

The application of strobilurin fungicides in combination with dithiocarbamate compounds significantly increased leaf area at all growth stages. The increase in leaf area due to the spray of pyraclostrobin + metiram @ 1500 g ha^{-1} was upto15.82% over control (Table 2). Leaf area influences radiant energy interception and shows positive relationship with net photosynthetic activity (Yan *et al.,* 2007). Jaleel *et al.* (2007) observed a significant reduction in leaf size but increased number of leaves due to the application of high concentration of strobilurin. However, higher leaf area in strobilurin treated plants was attributed to the delay in leaf senescence or abscission (Ishikawa *et al.*, 2012; Joshi *et al.* 2014) which may be a manifestation of increased chlorophyll content. The reduction in leaf size under triazole treatment was induced by the lack of adequate gibberellins biosynthesis and increased number of cells per unit area in palisade and spongy layer of leaf (Gopi *et al.*, 2007). The improvement in yield due to triazole alone or in combination with strobilurin reflected greater green leaf area duration associated with improved disease control (Ruske *et al.,* 2003) and prolonged grain filling. The application of triazoles and strobilurins recorded higher leaf area, largely due to delay in leaf senescence and thus to the maintenance of a photosynthetically active area over a longer time (Grossman *et al.,* 1999).

Total dry matter production (TDMP) represents direct relationship between photosynthesis and yield. Chilli crop showed a significant increase in TDMP at all growth stages in response to the application of various concentrations of strobilurin fungicides. Foliar application of trifloxystrobin + tebuconazole @ 400 g ha^{-1} showed a significant increase in total dry matter accumulation over other treatments (Table 3). The analysis of data on TDMP showed maximum increase of 36.7% over control. These observations are in line with Lima *et al*. (2012) in case of banana. The beneficial effect of trifloxystrobin + tebuconazole 75 WG in improving biomass production has also been noticed by Nagajothi (2013) in rice. Pedersen and Lauer (2004) and Nagajothi (2013) have attributed increase in total biomass to the biomass production in rice. The two strobilurin fungicides, kresoxim-methyl and trifloxystrobin, each mixed with a triazole compound enhanced dry matter production in winter wheat (Ishikawa *et al.*, 2012). Glaab and Kaiser (1999) reported that apart from fungicidal effects, strobilurins such as pyraclostrobin can cause long-term changes in

Table 3: Effect of strobilurin fungicides on total dry matter production (g $plant^{-1}$) at different growth stages in chilli

Treatments	30 DAT	60 DAT	90 DAT	120 DAT
Untreated control	8.54	34.20	80.72	88.55
Trifloxystrobin + tebuconazole @ 300 g ha^{-1}	8.45	40.99	106.01	115.06
Trifloxystrobin + tebuconazole @ 350 g ha^{-1}	8.68	43.03	111.17	120.76
Trifloxystrobin + tebuconazole @ 400 g ha^{-1}	8.45	47.06	126.30	140.03
Carbendazim 50 WP @ 500 g ha^{-1}	8.08	35.82	87.62	97.26
Pyraclostrobin + metiram 60 WG @ 1500 g ha^{-1}	8.66	44.96	120.03	130.24
Azoxystrobin 23 SC @ 500 mL ha^{-1}	8.14	40.24	104.64	114.71
Mean	8.43	41.39	105.21	115.22
S.E.	0.07	0.38	0.98	1.07
$CD_{0.05}$	ns	0.76	1.99	2.16

Table 4: Effect of strobilurin fungicides on yield and yield components in chilli

Treatments	No. of flowers ($plant^{-1}$)	No of fruits ($plant^{-1}$)	Green chilli yield (g $plant^{-1}$)
Untreated control	460.48	173.39	799.37
Trifloxystrobin + tebuconazole @ 300 g ha^{-1}	469.95	202.51	821.63
Trifloxystrobin + tebuconazole @ 350 g ha^{-1}	475.00	203.93	836.10
Trifloxystrobin + tebuconazole @ 400 g ha^{-1}	483.48	215.28	919.93
Carbendazim 50 WP @ 500 g ha^{-1}	464.04	182.36	795.13
Pyraclostrobin + metiram 60 WG @ 1500 g ha^{-1}	476.96	210.45	872.71
Azoxystrobin 23 SC @ 500 mL ha^{-1}	472.01	195.86	811.73
Mean	471.70	197.68	836.65
S.E.	4.28	1.82	7.62
$CD_{0.05}$	8.66	3.69	15.41

the metabolism and growth of the treated plants resulting in higher biomass and yield (Kanungo and Joshi, 2014). Moreover, increase in biomass paralleled with proportional increases in starch and protein. The shoot and root dry weights in carrot increased steadily as a result of hexaconazole and paclobutrazol increment which was related to the ability of triazoles to enhance cytokinin level thereby cell division and dry weight (Gopi *et al.,* 2007).

Yield is polygenic nature and is influenced by several factors (both internal and external) throughout the crop growth period. In present study, the combined application of strobilurin (trifloxystrobin) and triazole (tebuconazole) @ 400 g ha^{-1} gave highest number of flowers (483.48) and fruits (215.28) $plant^{-1}$ which increased the economic yield (919.93 g $plant^{-1}$) to an extent of 33.9% over control (799.37 g $plant^{-1}$). The increase in biomass in present study appears to have improved grain yield as well (Table 4). Maximum green chilli yield of 20.44 t ha^{-1} was obtained with treatment trifloxystrobin + tebuconazole applied as Nativo @ 400 g ha^{-1} which was 13% higher than untreated control (15.26 t ha^{-1}). Similar yield increases due to strobilurin-use have been reported by Sundravadana *et al.* (2008) and Bag (2009) in rice and Blandino and Reyneri (2009) in wheat. Strobilurins like pyraclostrobin induced non-fungicidal physiological changes including darker leaves, delayed leaf senescence, increased stress tolerance and more plant biomass and grain yield in wheat, barley and tobacco (Grossmann *et al*., 1999; Bayles and Hilton, 2000). Muhammad Ijaz (2012) reported that foliar application of azoxystrobin promoted seed yield components like 1000- grain weight, pods $plant^{-1}$ and number of seeds $plant^{-1}$ in oilseed rape. Ryan *et al.* (2011) confirmed that strobilurin application enhanced the seed mass and seed yield in soybean due to extended leaf life. The application of strobilurin at different growth stages consistently increased yield, 1000- grain weight and specific grain weight in wheat (Ruske *et al.,* 2003).

The disease incidence of chilli leaf curl complex, leaf spot and anthracnose was lessened by fungicidal treatments in comparison to untreated control (Table 5). However, combined use of

Table 5: Effect of strobilurin fungicides on pest and disease incidence of chilli

Treatments	Percent disease index		
	CLCC*	Leaf spot	Anthracnose
Untreated control	12.55	27.76	11.60
Trifloxystrobin + tebuconazole @ 300 g ha^{-1}	8.2	18.51	6.53
Trifloxystrobin + tebuconazole @ 350 g ha^{-1}	6.25	16.68	5.32
Trifloxystrobin + tebuconazole @ 400 g ha^{-1}	5.6	14.55	4.43
Carbendazim 50 WP @ 500 g ha^{-1}	7.3	20.04	8.35
Pyraclostrobin + metiram 60 WG @ 1500 g ha^{-1}	6.15	15.36	5.02
Azoxystrobin 23 SC @ 500 mL ha^{-1}	6.55	18.53	6.26
Mean	7.51	18.78	6.79
S.E.	0.22	0.19	0.05
$CD_{0.05}$	0.45	0.38	0.11

*CLCC = chilli leaf curl complex

trifloxystrobin and tebuconazole @ 400 g ha^{-1} showed lowest disease index of 5.60, 5.34 and 4.43%, respectively. The results suggested that decrease in disease incidence was one of the reasons for increased yield in chilli. Strobilurin fungicides reportedly are associated with yield increase due to higher photosynthetic rate by sustaining the photosynthetic life of canopy during grain filling in wheat (Pepler *et al*., 2005). Strobilurins have the ability to prolong the duration of leaf area than triazoles (Bryson *et al*., 2000). Applications of strobilurin compounds increase crop yield likely through better disease management (Godwin *et al.*, 2000).

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